Chemistry of 2-arylhydrazonals: utility of substituted 2-arylhydrazono-3-oxoalkanals as precursors for 3-oxoalkanonitriles, 3-aminoisoxazole and 1,2,3- and 1,2,4-triazoles

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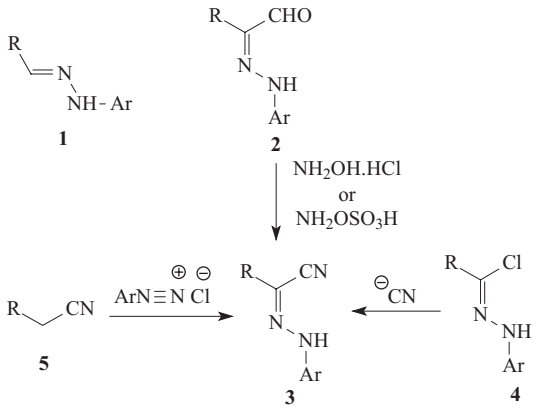
Efficient routes to 2-arylhydrazono-3-oxoalkanonitriles, 1,2,3- and 1,2,4-triazoles, and 3-aminoisoxazole utilising the oximes of the title hydrazones are reported. The behaviour of the oximes on pyrolysis in the gas phase and by flash vacuum is analysed. X-ray crystallography were used to confirm the structure of the triazole **10b** and the 3-oxoalkanonitrile **12f**.

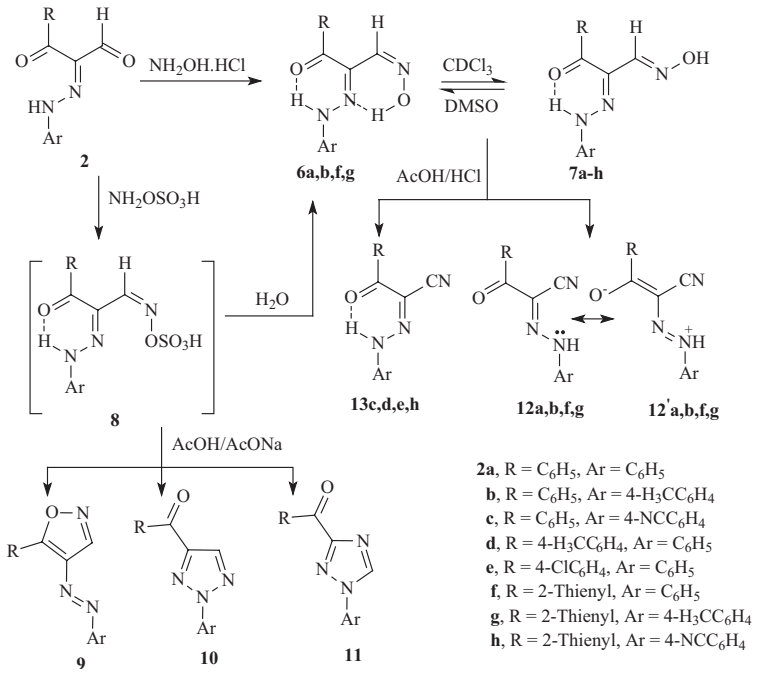
Keywords: arylhydrazonals, synthesis, oximes, triazoles, isoxazoles

The chemistry of substituted arylhydrazones **1** continues to receive considerable attention.[1,2] The utility of the 2-arylhydrazonals **2** as building blocks in heterocyclic chemistry has been extensively investigated in our laboratories in the past few years.[3-13] New efficient routes to cinnolines,[3,4] pyridines,[5-7] pyridazines,[8-10] pyrazoles and isoxazoles[11-13] have been described in our earlier work. Very recently, we reported an efficient synthesis of 2-arylhydrazono-3-oxoalkanonitrile **3** by reacting **2** with hydroxylamine hydrochloride in a domestic microwave oven.[14] Since this synthesis is more general in its scope than the established routes to **3** either from reaction of hydrazonyl halides **4** and cyanide ion[15] or via coupling 3-oxoalkanonitriles **5** with aromatic diazonium salts[16-18] (Scheme 1), it seemed of value to investigate further the scope of this synthesis. The investigation was further prompted by an interest in **2** as precursors to 4-arylazo-5-aminopyrazoles that are of potential use in D_2T_2 printing dyes, and in hair, fur and leather dyes.[19]



Scheme 1

The hydrazoaldehydes **2a–h** react readily with hydroxylamine hydrochloride in ethanolic sodium acetate to yield the corresponding oximes that are believed to exist in DMSO solution predominately in form **6**, whereas in $CDCl_3$ solution the *anti*-form **7** predominates (Scheme 2). The conversion



2a, R = C_6H_5, Ar = C_6H_5
b, R = C_6H_5, Ar = 4-$H_3CC_6H_4$
c, R = C_6H_5, Ar = 4-NCC_6H_4
d, R = 4-$H_3CC_6H_4$, Ar = C_6H_5
e, R = 4-ClC_6H_4, Ar = C_6H_5
f, R = 2-Thienyl, Ar = C_6H_5
g, R = 2-Thienyl, Ar = 4-$H_3CC_6H_4$
h, R = 2-Thienyl, Ar = 4-NCC_6H_4

Scheme 2

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of **6** to **7** is accompanied by shift of the oxime OH proton signal from δ_H *ca* 7 ppm to δ_H *ca* 12 ppm. Similar high field shift of oxime proton further upfield on isomerising *syn*- to *anti*-oximes has been reported earlier.[20] It appears that DMSO helps the preservation of the structural setting associated with form **7**.

The reaction of hydroxylamine-*O*-sulfonic acid with **2** in ethanol/sodium acetate at room temperature afforded the *syn*-oximes **6a,b,f,g**. It is believed that under such conditions the initially formed sulfonyl oximes **8** are gradually hydrolysed to **6**. On the other hand, and in contrast to reported formation of 3-oxoalkanonitriles from the reaction of **2** with hydroxylamine in microwave assisted synthesis,[14] compounds **2a,b,f,g** reacted with hydroxylamine-*O*-sulfonic acid in refluxing acetic acid in the presence of sodium acetate to yield products of condensation via elimination of water or sulfuric acid (Scheme 2).

The condensation products formulated as isoxazoles **9,** 1,2,3-triazoles **10** or 1,2,4-triazoles **11** are formed via initial Beckmann-like rearrangement of **8**. The structures of 1,2,3-triazoles **10** were established based on X-ray crystallographic determination (Fig. 1). Under similar reaction conditions, 3-oxoalkanonitriles **13c,d,h** were produced from the reaction of **2c,d,h** with hydroxylamine-*O*-sulfonic acid in acetic acid in the presence of sodium acetate. It is believed that the initially formed sulfonyl oximes **8** either undergo cyclisation into **10**, or eliminate sulfuric acid via a quazi-aromatic six-membered transition state (TS) to yield **13c,d,h** analogous to that suggested earlier[21,22] to account for the conversion of aldehyde oximes into nitriles in gas-phase thermolysis. The predominant reaction route seems to depend on the substitution pattern in the aryl moiety.

The reaction of **2e** with hydroxylamine-*O*-sulfonic acid afforded through **8e** a mixture of 1,2,3-triazole **10e** and isoxazole **9e** in the ratio of 2:1 as determined by peak integration of the singlet signals at δ_H 8.44 ppm and δ_H 8.76 ppm of the ^{1}H NMR spectrum. Attempts to separate **9e** and **10e** were unsuccessful.

Compounds **6a–h**/**7a–h** were converted quantitatively into nitriles upon reflux in acetic acid/hydrochloric acid mixture, and in much lower yield in pyridine. Under these conditions, the reaction is assumed to proceed through initial acylation which facilitates subsequent elimination (Scheme 2).

Although 3-oxoalkanonitriles **12a,f** have earlier been suggested[12,21] to exist in the hydrazone form **13,** in our hands some of the synthesised nitriles were found to exist in the non-hydrogen bonded *anti*-form **12a,b,f,g**, while the products of reaction of **7c–e,h** exist as **13**. ^{1}H NMR spectra of **12** revealed the NH proton at δ_H *ca* 9.5 ppm, while hydrazone **13** revealed typical hydrazone NH signal at δ_H *ca* 2.5 ppm. X-ray crystallographic determination (Fig. 2) confirmed the structure of compounds **12**. Although structure **13** is maintained through hydrogen bonding, structure **12** is also maintained albeit through resonance involving the delocalisation of the hydrazone lone pair of electrons to the carbonyl group. It seems that there is a delicate balance between these two structural factors, and thus the preferred structure seems to depend to a large extent on the nature of the substituent in the aryl group.

In order to establish the most likely pathways for the present transformations, the effect of substituents on reaction rates and mechanism of gas-phase pyrolysis was investigated, and a summary of the kinetic results are given in Table 1. The data include the reaction temperature range (389–454 K), the Arrhenius log A/s^{-1} (12.9 ± 3) and E_a/kJ mol^{-1} (133 ± 25), as well as the rate constant (k/s^{-1}) at 400 K of the eight oxime substrates. The results indicate a unimolecular reaction following first-order kinetics. It is of interest to note that studies using gas-phase pyrolysis provide valuable

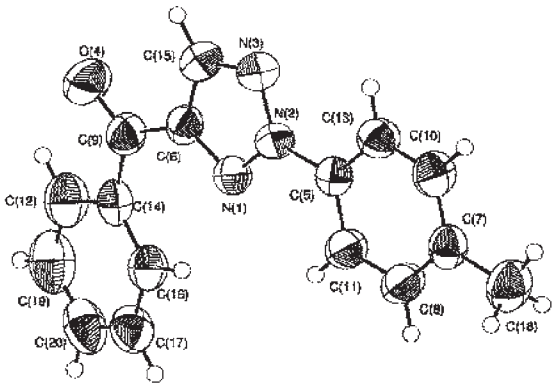


Fig. 1 X-ray crystal structure of compound **10b**.

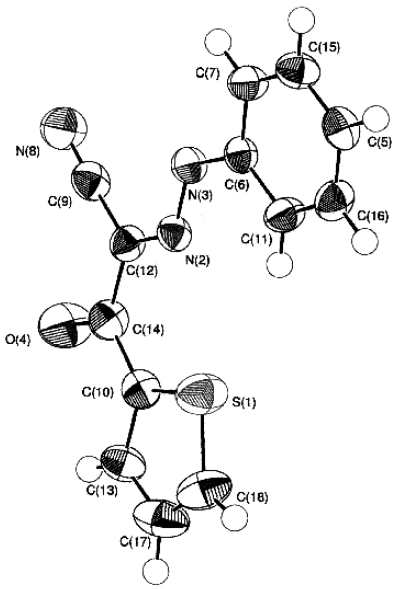


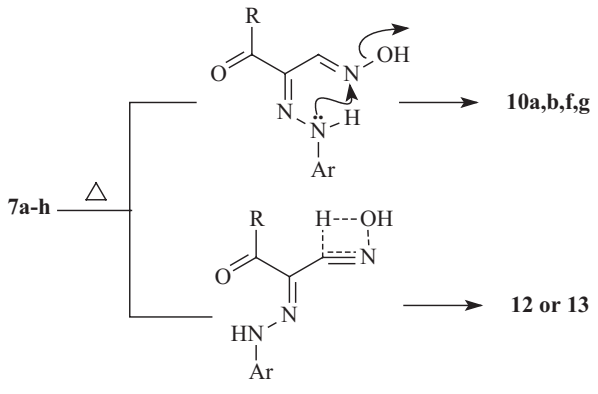
Fig. 2 X-ray crystal structure of compound **12f**.

information on intrinsic substituent and structural effects with no contribution to reaction or reactivity from reagent, catalyst or solvent. Hence, gas-phase cyclisation of **7a–h** was performed as a route to isoxazoles **9,** 1,2,3-triazoles **10,** 1,2,4-triazoles **11**, or conversion of the oximes to β-ketonitrile derivatives **12** and **13**. The first set of kinetic data and products of flash vacuum pyrolysis at 500 K involved transformation of compounds **7a–b** and **f–g** completely into 1,2,3-triazole derivatives **10a–b**, **f–g**. Initially it was thought that the positive inductive (+ I) effect of the *para* methyl group of compounds **2b** and **2 g** would slightly increase the nucleophilic character of the arylhydrazone nitrogen atom and possibly facilitate cyclisation. This is evident for the kinetic data from pyrolysis of compounds **2a–b**, but not so for **2f–g** (Table 1). However, all four compounds afforded the 1,2,3-triazoles **10a–b, f–g**. It is suggested that the initial step in these transformations involves attack by the lone pair of hydrazone nitrogen on the oxime nitrogen, which is then followed by elimination of H_2O (Scheme 3). It is of interest to note that, unlike compounds **7a–b** and **7f–g**, the pyrolysis of compounds **7c** and **7 h** under the same conditions followed a different reaction pathway. The products obtained for these substrates were the β-ketonitrile derivatives **13c,h**. It appears, therefore, that the electron-withdrawing group reduces the nucleophilicity of the arylhydrazone nitrogen, and thus the preferred route involves elimination of water from the oxime moiety through a four-membered TS similar to that considered for

Table 1 Kinetic data, Arrhenius parametres, and rate constants at 400 K for gas-phase pyrolysis of **6/7a–h**

Cpd	R	Ar	T/K	10^4 k/s^{-1}	Log A/s^{-1}	Ea/kJ mol^{-1}	10^{-5} k_{400K}
7a	C_6H_5	C_6H_5	388.6	0.095	14.78 ± 0.11	147.3 ± 0.05	3.56
			414.8	1.82			
			429.4	7.27			
			434.4	12.0			
			453.2	63.5			
7b	C_6H_5	4-CH_3-C_6H_4	409.4	2.63	14.06 ± 0.65	138.4 ± 0.27	9.65
			414.4	3.85			
			416.8	4.60			
			419.8	7.80			
			424.3	11.1			
			433.8	23.8			
			439.8	42.2			
7c	C_6H_5	4-CN-C_6H_4	397.2	1.09	10.49 ± 0.03	109.9 ± 0.01	13.6
			404.8	2.02			
			419.8	6.45			
			420.0	6.58			
			434.8	19.2			
7d	4-CH_3 C_6H_4	C_6H_5	400.2	0.06	12.23 ± 0.77	133.0 ± 0.33	0.727
			417.0	0.45			
			425.4	0.92			
			433.8	1.25			
			442.4	4.17			
			454.2	7.54			
7e	4-Cl-C_6H_4	C_6H_5	400.2	0.91	10.22 ± 0.18	109.2 ± 0.08	9.07
			408.6	1.84			
			434.2	11.4			
			442.4	22.8			
			450.8	35.7			
			450.8	36.1			
7f	2-thienyl	C_6H_5	399.0	0.21	13.21 ± 0.65	136.7 ± 0.07	2.33
			418.4	1.54			
			434.4	5.72			
			434.4	5.78			
			448.8	21.0			
			454.4	32.0			
			454.4	32.2			
7g	2-thienyl	4-CH_3-C_6H_4	421.8	1.96	15.88 ± 0.72	158.0 ± 0.31	1.79
			427.6	4.15			
			442.6	16.5			
			447.6	28.4			
7h	2-thienyl	4-CN-C_6H_4	399.9	.595	14.20 ± 0.37	141.1 ± 3.10	5.95
			416.4	3.18			
			425.8	7.60			
			429.8	10.6			
			439.8	30.5			
			444.8	41.3			

pyrolytic elimination of halogen acids from alkyl halides (Scheme 3). Since a completely non-polar TS would violate the Woodward rules, it is assumed that the N–OH bond is weakened to a much greater extent with concomitant development of partial charge in the proposed TS. Similar assumption has been made to account for the formation of such TS in analogous thermal gas-phase processes involving halogen acid elimination reactions (Scheme 3).[23]



Scheme 3 Gas-phase pyrolysis of **7a–h**.

In an attempt to present a more complete pattern of transformation of the oxime series, we have also studied the effect of substituents on the α-aryl moiety. It was initially envisaged that the cyclisation reaction of compound **7d** to yield the β-ketonitrile derivative **13d** would be enhanced by the (+ I) effect of the *para* methyl group. However, the kinetic data obtained shows that the electron-withdrawing group on the α-aryl moiety in **7e** enhanced reactivity *ca* 10-fold over **7d**. Besides, flash vacuum pyrolysis of compounds **7d–e** furnished mixed products that appear to be isoxazole **9d–e** and 1,2,3-triazole derivatives **10d–e** in a ratio of 1:1, with no trace of β-ketonitrile derivatives being observed. The mass spectra are compatible with both structures **9** and **10**. Moreover, the IR, ^{1}H NMR, and ^{13}C NMR spectral data match the proposed structures. IR spectra show signal for (CO) at ν = 1645 cm^{-1} and the absence of nitrile group peak at *ca* ν = 2220 cm^{-1}.

^{1}H NMR revealed the presence of H-3 signal of **9** at δ_H 8.46 and 8.43 ppm and δ_H 8.76 and 8.92 ppm. ^{13}C NMR revealed downfield signal at δ_C 188, 186 and 166, 168 ppm assigning CO for **9** and C-5 for **10**. All the remaining signals are in accordance with the proposed structures.

Compounds **2b,d** reacted with excess hydroxylamine-*O*-sulfonic acid in acetic acid in the presence of sodium acetate to yield products of molecular weight 278. These can thus be assigned as 5-aminoisoxazole **18**, 3-aminoisoxazole **16** or 5-aminotriazole **17**. It is assumed that under these conditions an initially formed nitrile **12** reacted further with another molecule of hydroxylamine-*O*-sulfonic acid yielding either the hydroxyiminonitrile **14** or the amidoxime **15.** The amidoxime **15** would either cyclise to 3-aminoisoxazole **16** or to 5-aminotriazole **17**, whereas the hydroxyimino-nitrile would cyclise to 5-aminoisoxazole **18**. Although the 3-aminoisoxazole **16** structure seems the more likely based on analogy with the well-established behaviour of 2-aryl-hydrazono-3-oxoalkanonitrile **12** towards hydroxylamine hydrochloride, confirmation of this deduction is imperative. Consequently, the oxoalkanonitriles **12** were treated with hydroxylamine-*O*-sulfonic acid in ethanolic sodium acetate to yield the amidoxime **15**, and cyclisation of the latter in sodium ethoxide afforded the 3-aminoisoxazole **16** that proved to be identical with the reaction products obtained by treatment of **2b,d** with excess of hydroxylamine-*O*-sulfonic acid in acetic acid in the presence of sodium acetate (Scheme 4). Moreover, the ^{13}C NMR shows absence of any signal at δ_C 186 ppm indicative of carbonyl group.

When compounds **2f,g** were similarly reacted with excess of hydroxylamine-*O*-sulfonic acid in acetic acid in the presence of sodium acetate, or when the amidoxime **15f,g** were treated with sodium ethoxide the 5-aminotriazole **17f,g** were produced together with 3-aminoisoxazole **16f,g**.

Experimental

All melting points are uncorrected. IR spectra were recorded in KBr with a Pye Unicam SP 1100 spectrophotometre. ^{1}H NMR spectra were recorded on a Varian EM-390 400 MHz spectrometre using $CDCl_3$ or [$^2H_6$] DMSO as solvent and TMS as internal standard. Chemical shifts δ are reported in ppm. Mass spectra were measured on an MS 30 and MS 9 (AEI) 70 Ev mass spectrometre. Microanalyses were performed on a LECO CHNS-932.

Crystallographic analysis

The crystals were mounted on a glass fiber. All measurements were performed on an ENRAF NONIUS FR 590. The data were collected at a temperature of 20 ± 1 °C using the ω scanning technique to a maximum of a 2θ of 27.12°. The structure was solved by direct method using SIR 92 and refined by full-matrix least squares.[24] Non-hydrogen atoms were refined anisotropically. Hydrogen atoms were located geometrically and were refined isotropically.

Crystal data

$C_{16}H_{13}N_3O_6$ **(10b)** M_r = 343.295, Monoclinic, *a* = 14.2998 (8), *b* = 5.2328 (3), *c* = 22.3717 (12) Å, V = 1335.19 (13), α = γ = 90.00°, β = 13. (18) × 10°, Space group: $P2_1/c$, Z = 3, D_x = 1.281 Mg m^{-3}, θ_{max} = 23.03°. Full data can be obtained on request from the CCDC.[25]

$C_{13}H_9N_3OS$ **(12f)** M_r = 255.299, Monoclinic, *a* = 24.3588 (7), *b* = 5.4024 (2), *c* = 21.3344 (9) Å, V = 2387.7 (2), α = γ = 90.00°, β = 121.739 (2)°, Space group: C2/c, Z = 8, D_x = 1.420 Mg m^{-3}, θ_{max} = 27.36°. Full data can be obtained on request from the CCDC.[26]

General procedure for preparation of compounds **2c,h**

Compounds **2c** and **2 h** were prepared following procedures published for **2a,b** and **2d–g** which involve coupling the corresponding enaminones with benzonitrile diazonium chloride.[10]

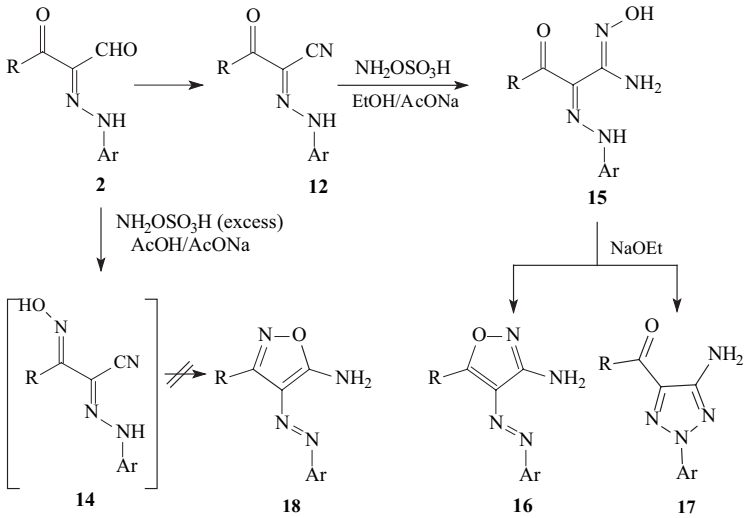
4-[N-(1–Formyl-2-oxo-2-phenylethylidene)hydrazono]benzonitrile (**2c**): The compound was obtained as yellow crystals from dioxane; yield (62 %, 1.7 g); m.p. 176–178 °C; IR (KBr): ν/cm^{-1}: 2887 (NH), 2229 (CN), 1657 and 1637 (C=O). MS: *m/z* = 277 (M$^+$); ^{1}H NMR (DMSO-d_6): δ (ppm) = 7.56–7.57 (m, 3H, Ar–H), 7.65–7.76 (m. 2H, Ar–H), 7.81–7.91 (m, 4H, benzonitrile-H), 9.59 (s, 1H, NH D_2O exchangeable), 10.00 (s, 1H, CHO). Anal. Calcd. for $C_{16}H_{11}N_3O_2$ (277.27): C 69.30, H 4.00, N 15.16. Found C 69.35, H 4.15, N 15.26.

4-[N-(1-Formyl-2-oxo-2-thiophen-2-yl-ethylidene)hydrazono] benzonitrile (**2 h**): The compound was obtained as yellow crystals from dioxane, yield (65 %, 1.83 g); m.p. 197–198 °C; IR (KBr): ν/cm^{-1}: 2882 (NH), 2227 (CN), 1653 and 1602 (C=O); MS: *m/z* = 283 (M$^+$); ^{1}H NMR (DMSO-d_6): δ (ppm) = 7.31 (m. 1H, thienyl 4-H), 7.82 (d, 2H. *J* = 8.4 Hz, benzonitrile-H), 7.93 (d, 2H, *J* = 8.4 Hz, benzonitrile-H), 8.07 (d, 1H, *J* = 5 Hz, thienyl 3-H), 8.11 (d, 1H, *J* = 5 Hz, Thienyl 5-H), 10.00 (s, 1H, CHO), 13.97 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{14}H_9N_3O_2S$ (283.24): C 59.36, H 3.18, N 14.84, S 11.30. Found C 59.63, H 3.31, N 14.90, S 11.28.

Reactions of the arylhydrazonopropanals with hydroxylamine-O-sulfonic acid for the preparation of syn-oximes **6a,b** *and* **6f,g**

To a cold solution of 0.1 mmol of each of compounds **2a,b** and **2f,g** in 10 ml ethanol, a prepared solution of hydroxylamine-*O*-sulfonic acid (0.069 g, 0.1 mmol) and sodium acetate (0.2 mmol) in water (3 ml) was added dropwise. The mixture was stirred for 3 h and allowed to warm up to room temperature. During this time a yellow precipitate is formed. The reaction mixture was then poured into water, filtered off and recrystallised as yellow crystals from ethanol.

3-Oxo-3-phenyl-2-(phenylhydrazono)propanal oxime (**6a**): Yield (86 %, 2.3 g); m.p. 209–210 °C (lit.[11] m.p. 202–204); IR (KBr): ν/cm^{-1}: 3430 (OH), 3058 (NH) and 1602 (CO); MS: *m/z* = 267 (M$^+$); ^{1}H NMR (DMSO-d_6): δ (ppm) = 7.11 (t, 1H, *J* = 7.4 Hz, Ar–H), 7,21 (d, 2H, *J* = 7.9 Hz, Ar–H), 7.35 (t, 2H, *J* = 7.9 Hz, Ar–H), 7.49 (t, 2H. *J* = 7.9 Hz, Ar–H), 7.56–7.60 (m, 4H, Ar–H and OH, D_2O exchangeable), 8.02 (d, 2H, *J* = 7.4 Hz, Ar–H), 8.76 (s, 1H,



Scheme 4

oxime-CH), 12.53 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{15}H_{13}N_3O_2$ (267.28): C 67.40, H 4.90, N 15.72. Found C 67.82, H 4.91, N15.86.

3-Oxo-3-phenyl-2-(p-tolylhydrazono)propanal oxime (**6b**: Yield (85 %, 2.4 g); m.p. 201–202 °C; IR (KBr): ν/cm^{-1}: 3433 (OH), 3058 (NH), 1635 (CO); MS: *m/z* = 281 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 2.34 (s, 3H, CH_3), 7.10 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 7.15 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 7.46–7.50 (m, 3H, phenyl-H and OH, D_2O exchangeable), 7.56 (t, 1H, *J* = 7.4 Hz, phenyl-H), 7.96 (d, 2H, *J* = 7.4 Hz, phenyl-H), 8.76 (s, 1H, oxime-CH), 12.53 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{16}H_{15}N_3O_2$ (281.30): C 68.31, H 5.38, N 14.94. Found C 68.28, H 5.40, N 15.33.

3-Oxo-2-phenylhydrazono-3-(thiophen-2-yl)propanal oxime (**6f**): Yield (80 %, 2.2 g); m.p. 222–223 °C; IR (KBr): ν/cm^{-1}: 3178 (OH), 3060 (NH), 1589 (CO); MS: *m/z* = 273 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 7.14–7.20 (m, 2H, phenyl-H and thienyl 4-H), 7.41–7.46 (m, 4H, phenyl-H), 7.52 (s, 1H, OH, D_2O exchangeable), 7.73 (d, 1H, *J* = 5 Hz, thienyl 3-H), 8.19 (d, 1H, *J* = 5 Hz, thienyl 5-H), 8.77 (s, 1H, oxime-CH), 12.61 (br s, 1H. NH, D_2O exchangeable). Anal. Calcd. for $C_{13}H_{11}N_3O_2S$ (273.24): C 57,14, H 4.06, N 15.38, S 11.72. Found C 57.49, H 4.07, N 15.47, S 11.66.

3-Oxo-3-thiophen-2-yl-2-(p-tolylhydrazono)propanal oxime (**6 g**): Yield (87 %, 2.5 g); m.p. 200–201 °C; IR (KBr): ν/cm^{-1}: 3220 (OH), 2908 (NH) and 1602 (C=O); MS: *m/z* = 287 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 2.41 (s, 3H, CHs), 7.18 (t, 1H, *J* = 5 Hz, Thienyl 4-H), 7.23 (d. 2H, *J* = 8.0 Hz, *p*-tolyl-H), 7.35 (d, 2H, *J* = 8.0 Hz, *p*-tolyl-H). 7.53 (s, 1H, OH, D_2O exchangeable), 7.73 (d, 1H, *J* = 5.0 Hz, thienyl 3-H), 8.18 (d, 1H, *J* = 5.0 Hz, thienyl 5-H), 8.77 (s, 1H, oxime-CH), 12.62 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{14}H_{13}N_3O_2S$ (287.27): C 58.53, H 4.56, N 14.63, S 11.14. Found C 58.73, H 4.66, N 14.69, S 11.13.

Reactions of the arylhydrazonopropanals **2a–h** *with hydroxylamine hydrochloride for the preparation of anti-oxime* **7a–h**

To a cold solution of 0.1 mmol of each of compounds **2a–h** in 10 ml ethanol, a prepared solution of hydroxylamine hydrochloride (0.069 g, 0.1 mmol) and sodium acetate (0.2 mmol) in water (3 ml) was added dropwise. The mixture was stirred for 3 h and allowed to warm up to room temperature. During this time a yellow precipitate is formed. The reaction mixture is then poured into water, filtered off and recrystallised from ethanol to give yellow needles of **7a–h**.

3-Oxo-3-phenyl-2-phenylhydrazonopropanal oxime (**7a**): Yield (87 %, 2.3 g); m.p. 210–212 °C (lit.[11] m.p. 202–204); IR (KBr): ν/cm^{-1}: = 3222 (OH), 3058 (NH) and 1600 (CO); MS: *m/z* = 267 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 7.07 (t, 1H, *J* = 7.4 Hz, Ar–H), 7.15 (d, 2H, *J* = 7.9 Hz, Ar–H), 7.38 (t, 2H, *J* = 7.9 Hz, Ar–H), 7.53 (t, 2H, *J* = 7.8 Hz, Ar–H), 7.62 (t, 1H, *J* = 7.4 Hz, Ar–H), 7.87 (d. 2H. *J* = 7.4 Hz, Ar–H), 8.45 (s, 1H, oxime-CH), 12.44 (br s, 1H, OH, D_2O exchangeable), 12.75 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{15}H_{13}N_3O_2$ (267.28): C 67.40, H 4.90, N 15.72. Found C 67.27, H 4.97, N 16.07.

3-Oxo-3-phenyl-2-(p-tolylhydrazono)propanal oxime (**7b**). Yield (89 %, 2.5 g); m.p. 202–203 °C; IR (KBr): ν/cm^{-1}: 3433 (OH), 3058 (NH), 1635 (CO); MS: *m/z* = 281 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 2.26 (s, 3H, CH_3), 7.06 (d, 2H. *J* = 8.4 Hz, *p*-tolyl-H), 7.19 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 7.53 (t, 2H, *J* = 7.4 Hz, phenyl-H), 7.61 (t, 1H, *J* = 7.4 Hz, phenyl-H), 7.86 (d, 2H, *J* = 7.4 Hz, phenyl-H), 8.45 (s, 1H, oxime-CH), 12.14 (br s, 1H, OH, D_2O exchangeable), 12.77 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{16}H_{15}N_3O_2$ (281.30); C 68.31, H 5.38, N 14.94. Found C 68.40, H 5.36, N15.31.

4-{N-[1-(Hydroxyiminomethyl)-2-oxo-2-phenyl]hydrazono}benzonitrile (**7c**). Yield (85 %, 2.5 g); m.p. 207–209 °C; IR (KBr): ν/cm^{-1}: 3437 (OH), 3186 (NH), 2218 (CN) and 1602 (CO); MS: *m/z* = 292 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 7.24 (d, 2H, *J* = 8.4 Hz, benzonitrile-H), 7.54 (t, 2H, *J* = 7.7 Hz, Ar–H), 7.63 (t, 1H, *J* = 7.4 Hz, Ar–H), 7.81 (d, 2H, *J* = 7.4 Hz, Ar–H), 7.88 (d, 2H, *J* = 8.4 Hz, benzonitrile–H), 8.42 (s, 1H, oxime-CH), 12.34 (br s, 1H, OH, D_2O exchangeable), 12.68 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{16}H_{12}N_4O_2$ (292.29): C 65.75, H 4.14, N 19.17. Found C 65.69, H 4.18, N 19.18.

3-Oxo-2-phenylhydrazono-3-p-tolylpropanal oxime (**7d**): Yield (89 %, 2.5 g); m.p. 214–215 °C; IR (KBr): ν/cm^{-1}: 3272 (OH), 3064 (NH), 1615 (CO); MS: *m/z* = 281 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 2.41 (s, 3H, CH_3), 7.10 (t, 1H, *J* = 7.5 Hz, phenyl-H), 7.16 (d, 2H,. 7 = 8.04 Hz, tolyl-H), 7.34 (d, 2H, *J* = 7.5 Hz, phenyl-H), 7.38 (t, 2H, *J* = 7.8 Hz, phenyl-H), 7.81 (d, 2H, *J* = 8.04 Hz, tolyl-H), 8.43 (s, 1H, oxime-CH), 12.14 (br s, 1H, OH, D_2O exchangeable), 12.73 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{16}H_{15}N_3O_2$ (281.30): C 68.31. H 5.38, N 14.94. Found C 68.34, H 5.34, N 15.04.

3-(4-Chlorophenyl)-3-oxo-2-phenylhydrazonopropanal oxime (**7e**): Yield (73 %, 2.2 g); m.p. 212–214 °C; IR (KBr): ν/cm^{-1}: 3471 (OH), 3186 (NH), 1598 (CO); MS: *m/z* = 301 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 7.10 (t, 1H, *J* = 7.4 Hz, phenyl-H), 7.15 (d, 2H, *J* = 7.5 Hz, phenyl-H), 7.39 (t, 1H. *J* = 7.5 Hz, phenyl-H), 7.61 (d, 2H, *J* = 8.5 Hz, *p*-chlorophenyl-H), 7.89 (d, 2H. *J* = 8.5 Hz, *p*-chlorophenyl-H), 8.44 (s, 1H, oxime-CH), 12.34 (br s, 1H, OH, D_2O exchangeable), 12.70 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{15}H_{12}N_3O_2Cl$ (301.76): C 59.65, H 3.97, N 13.92. Found C 59.66, H 4.06, N 13.97.

3-Oxo-2-(phenylhydrazono)-3-(2-thienyl)propanal oxime (**7f**): Yield (80 %, 2.2 g); m.p. 218–220 °C; IR (KBr): ν/cm^{-1} 3509 (OH), 3283 (NH) and 1598 (CO); MS: *m/z* = 273 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 7.15 (t, 1H, *J* = 7.3 Hz, phenyl-H), 7.42 (t, 1H, *J* = 5.0 Hz, thienyl 4-H), 7.42 (d, 2H, *J* = 7.5 Hz, phenyl-H), 7.47 (t, 2H, *J* = 7.5 Hz, phenyl-H), 8.06–8.08 (m, 2H, thienyl 3-H and 5-H), 8.46 (s, 1H, oxime-CH), 12.25 (br s, 1H, OH, D_2O exchangeable), 12.89 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{13}H_{11}N_3O_2S$ (273.24): C 57.14, H 4.06, N 15.38, S 11.72. Found C 56.79, H 4.08, N15.32, S 11.52.

3-Oxo-3-2-(p-tolylhydrazono(2-thienyl)propanal oxime (**7g**): Yield (83 %, 2.4 g); m.p. 200–201 °C; IR (KBr): ν/cm^{-1}: 3529 (OH), 3293 (NH) and 1578 (CO); MS: *m/z* = 287 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 2.31 (s, 3H, CH_3), 7.25–7.28 (m, 3H, *p*-tolyl-H and thienyl 4-H), 7.32 (d. 2H, *J* = 8.0 Hz, *p*-tolyl-H), 8.04 (d, 1H, *J* = 5.0 Hz, thienyl 3-H), 8.06 (d, 1H, *J* = 5.0 Hz, thienyl 5-H), 8.46 (s, 1H, oxime-CH), 12.16 (br s, 1H, OH, D_2O exchangeable), 12.88 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{14}H_{13}N_3O_2S$ (287.27); C 58.53, H 4.56, N 14.63, S 11.14. Found C 58.81, H 4.81, N 14.69, S 11.29.

4-[N-(1-Hydroxyiminomethyl)-2-oxo-2-(2-thienyl)-ethylidene] hydrazonobenzonitrile (**7h**): Yield (77 %, 2.3 g); m.p. 243–245 °C; IR (KBr): ν/cm^{-1}: 3437 (OH), 3179 (NH), 2222 (CN) and 1601 (CO); MS: *m/z* = 298 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 7.29 (t, 1H, *J* = 5.0 Hz, thienyl 4-H), 7.49 (d, 2H, *J* = 8.0 Hz, benzonitrile-H), 7.88 (d, 2H, *J* = 8.0 Hz, benonitrile-H), 8.08–8.10 (m, 2H, thienyl 3-H and 5-H), 8.42 (s, 1H, oxime-CH), 12.40 (br s, 1H, OH, D_2O exchangeable), 12.83 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{14}H_{10}N_4O_2S$ (298.25): C 56.38, H 3.38, N 18.79, S 10.73. Found C 56.69, H 3.44, N 18.62, S 10.64.

Reactions of arylhydrazonopropanals **2a,b** *and* **2f,g** *with hydroxylamine-O-sulfonic acid under acetic acid/sodium acetate condition for the preparation of* **10a,b,f,g**

To a solution of 0.1 mmol of each of compound **2a,b,f,g** in 10 ml acetic acid, hydroxylamine-*O*-sulfonic acid (0,069 g, 0.1 mmol) and sodium acetate (0.2 mmol) was added. The mixture was heated under reflux for 1 h. The reaction mixture was then poured into water, filtered off and recrystallised from ethanol to give yellow needles of **10a,b,f,g.**

Phenyl(2-phenyl-2H-1,2,3-triazol-4-yl)methanone (**10a**): Yield (70 %, 1.7 g); m.p. 158–159 °C; IR (KBr): ν/cm^{-1}: 1630 (C=O); MS: *m/z* = 249 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 7.44–7.55 (m, 4H, Ar–H), 7.65–7.77 (m, 2H, Ar–H), 8.00–8.20 (m, 4H, Ar–H), 9.08 (s, 1H, triazolyl-H). Anal. Calcd. for $C_{15}H_{11}N_3O$ (249.26): C 72.27, H 4.45, N 16.86. Found C 72.23, H 4.68, N 16.78.

Phenyl-(2-p-tolyl-2H-1,2,3-triazol-4-yl)methanone (**10b**): Yield (76 %, 2.0 g); m.p. 98–99 °C; IR (KBr): ν/cm^{-1}: 1646 (C=O); MS: *m/z* = 263 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 2.45 (s, 3H, CH_3), 7.45 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 7.57 (t, 2H, *J* = 7.6 Hz, phenyl-H), 7.67 (t, 1H, *J* = 7.6 Hz, phenyl-H), 8.05 (d, 2H, *J* = 7.6 Hz, phenyl-H), 8.38 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 8.42 (s, 1H, triazolyl-H). ^{13}C NMR (DMSO-d_6): δ (ppm) = 186.20, 147.74, 139.30, 139.04, 137.85, 137.17, 134.00, 131.02, 130.95, 129.10, 119.97 and 21.73. Anal. Calcd. for $C_{16}H_{13}N_3O$ (263.29): C 72.98, H 4.98, N 15.96. Found C 72.93, H 5.08, N 16.08.

(2-Phenyl-2H-1,2,3-triazol-4-yl)2-thienyl-methanone (**10f**). Yield (70 %, 1.8 g); m.p. 92–93 °C; IR (KBr): ν/cm^{-1}: 1621 (C=O); MS: *m/z* = 255 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 7.39 (t, 1H, *J* = 5.0 Hz, thienyl 4-H), 7.55 (t, 1H, *J* = 7.0 Hz, phenyl-H), 7.67 (t, 2H, *J* = 7.0 Hz, phenyl-H), 8.19 (d, 2H, *J* = 7.0 Hz, phenyl-H), 8.22 (d, 2H, *J* = 5.0 Hz, thienyl 3-H), 8.60 (d, 1H, *J* = 5.0 Hz, thienyl 5-H), 8.74 (s, 1H, triazolyl 5-H). ^{13}C NMR (DMSO-d_6): δ (ppm) = 177.36 (CO), 147.65, 142.44, 139.74, 139.46, 137.98, 137.38, 131.04, 130.28, 130.09 and 120.305. Anal. Calcd. for $C_{13}H_9N_3OS$ (255.23): C 61.17, H 3.55, N 16.47, S 12.54. Found C 61.09, H 3.54, N 16.41, S 12.55.

(2-thienyl)(2-p-tolyl-2H-1,2,3-triazoI-4-yl)methanone (**10 g**): Yield (82 %, 2.2 g); m.p. 144–145 °C; IR (KBr): ν/cm^{-1}: 1624 (C=O); MS: *m/z* = 269 (M^+); ^{1}H NMR ($CDCl_3$): δ (ppm) = 2.46 (s, 3H, CH_3), 7.27 (t, 1H, *J* = 5.0 Hz, thienyl 4-H), 7.35 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 7.80 (d, 1H, *J* = 5.0 Hz, thienyl 3-H), 8.07 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 8.41 (s, 1H, triazolyl 5-H), 8.57 (d, 1H, *J* = 5.0 Hz, thienyl 5-H). ^{13}C NMR (DMSO-d_6): δ (ppm) = 177.57, 147.43, 142.71, 139.35, 138.38, 137.82, 136.19, 135.83, 130.61, 128.93, 119.90 and 21.74. Anal. Calcd. for $C_{14}H_{11}N_3OS$ (269.25): C 62.45, H 4.12, N 15.61, S 11.88. Found C 62.69, H 4.30, N 15.73, S 12.24.

Reactions of **6a,b,f,g** *or* **7a**-*h under acetic acid/HC1 condition for the preparation of* **12a,b,f,g** *and* **13c,d,e,h**

Each of the *syn*- or *anti*-oxime derivatives **6a,b,f,g** or **7a**–**h** (0.1 mmol) in a mixture of acetic acid (7 ml) and HC1 (3 ml) was heated under reflux for 1 h to ensure that the oximes have dissolved. The reaction mixture was concentrated to 5 ml. The resulting yellow precipitate was filtered off and recrystallised from ethanol.

3-Oxo-3-phenyl-2-phenylhydrazonopropanenitrile (**12a**): This compound was obtained as yellow crystals from ethanol, in yield (92 %, 2.3 g); m.p. 136–137 °C; (lit.[11] m.p. 134–135 °C).

3-Oxo-3-phenyl-2-(p-tolylhydrazono)-propanenitrile (**12b**): Yield (91 %, 2.4 g); m.p. 150–152 °C; IR (KBr): ν/cm^{-1}: 3223 (NH), 2211 (CN), 1644 (CO); MS: *m/z* = 263 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 2.41 (s, 3H, CHs), 7.17 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 7.22 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 7.53 (t, 2H, *J* = 7.6 Hz, phenyl-H), 7.63 (t, 1H, *J* = 7.6 Hz, phenyl-H), 8.02 (d, 2H, *J* = 7.4 Hz, phenyl-H), 9.46 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{16}H_{13}N_3O$ (263.29): C 72.98, H 4.98, N 15.96. Found C 72.76, H 5.05, N 15.96.

3-Oxo-2-(phenylhydrazono)-3-(2-thienyl)-propanenitrile (**12f**): Yield (94 %, 2.4 g); m.p. 206–207 °C (lit.[12] m.p. 214 °C); IR (KBr): ν/cm^{-1}: 3200 (NH), 2214 (CN) and 1623 (CO); MS: *m/z* = 255 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 7.23–7.25 (m, 2H, phenyl-H and thienyl 4-H), 7.44–7.52 (m, 4H, phenyl-H), 7.79 (d, 1H, *J* = 5.0 thienyl 3-H), 8.22 (d, 1H, *J* = 5.0 thienyl 5-H), 9.48 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{13}H_9N_3OS$ (255.23): C 61.17, H 3.55, N 16.47, S 12.54. Found C 61.18, H 3.77, N 16.35, S 12.47.

3-Oxo-3-(2-thienyl)-2-(p-tolylhydrazno)propanenitrile (**12g**): Yield (93 %, 2.5 g); m.p. 208–209 °C; IR (KBr): ν/cm^{-1}: 3200 (NH), 2215 (CN) and 1617 (CO); MS: *m/z* = 269 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 2.41 (s, 3H, CH3), 7.23 (t, 1H, *J* = 5 Hz, thienyl 4-H), 7.32 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 7.35 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 7.79 (d, 1H, *J* = 5.0 Hz, thienyl 3-H), 8.22 (d, 1H, *J* = 5.0 Hz, thienyl 5-H), 9.45 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{14}H_{11}N_3OS$ (269.25): C 62,45, H 4.12, N 15.61, S 11.88. Found C 62.15, H 4.12, N 15.61, S 11.88.

4-[N-(1-Cyano-2-oxo-2-phenylethylidene)hydrazino]benzonitrile (**13c**): This compound was obtained as brownish crystals from dioxane, in yield (84 %, 2.3 g); m.p. 242–244 °C; IR (KBr): ν/cm^{-1}: 3206 (NH), 2226 (CN) and 1651 (CO); MS: *m/z* = 274 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 7.47 (d, 2H. *J* = 8.4 Hz, benzonitrile-H), 7.56 (t, 2H, *J* = 7.5 Hz, phenyl-H), 7.67 (t. 1H, *J* = 7.5 Hz, phenyl-H), 7.85 (d, 2H, *J* = 8.4 Hz, benzonitrile-H), 7.88 (d, 2H, *J* = 7.5 Hz, phenyl-H), 12.58 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{16}H_{10}N_4O$ (274.27): C 70.06, H 3.68, N 20.43. Found C 70.02, H 3.84, N 20.10.

3-Oxo-2-phenylhydrazono-3-p-tolyl-1-propionitrile (**13d**): Yield (95 %, 2.5 g); m.p. 153–154 °C; IR (KBr): ν/cm^{-1}: 3220 (OH), 3062 (NH), 2217 (CN), 1642 (CO); MS: *m/z* = 263 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 2.41 (s, 3H, CH_3), 7.16 (t, 2H, *J* = 7.5 Hz, phenyl-H), 7.35 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 7.39–7.45 (m, 4H, phenyl-H), 7.81 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 12.33 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{16}H_{13}N_3O$ (263.29): C, 72.98, H 4.98, N, 15.96. Found C, 72.75. H, 5.11, N, 15.97.

3-(4-Chlorphenyl)-3-oxo-2-phenylhydrazonopropionitrile (**13e**): This compound was obtained as orange crystals from dioxane, yield (92 %, 2.6 g); m.p. 181–182 °C; IR (KBr): ν/cm^{-1}: 3213 (NH), 2216 (CN) and 1650 (CO); MS: *m/z* = 283 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 7.16 (t, 2H, *J* = 7.5 Hz, phenyl-H), 7.39–7.43 (m, 4H, phenyl-H), 7.63 (t, 1H, *J* = 8.4 Hz, *p*-chlorophenyl-H). 7.90 (d, 2H, *J* = 8.4 Hz, *p*-chlorophenyl-H), 12.45 (br s, 1H. NH, D_2O exchangeable). Anal. Calcd. for $C_{15}H_{10}N_3OCl$ (283.76): C, 63.43, H, 3.52, N, 14.80. Found C, 63.25, H, 3.66, N, 14.87.

4-[N-(1-Cyano-2-oxo-2-(2-thienyl)-ethylidene)hydrazono]benzonitrile (**13 h**): This compound was obtained as brownish crystals from dioxane, yield (86 %, 2.4 g); m.p. 270–272 °C; IR (KBr): ν/cm^{-1}: 3231 (NH), 2222 (CN) and 1626 (CO); MS: *m/z* = 280 (M^+); ^{1}H NMR ($CDCl_3$): δ (ppm) = 7.24 (t, 1H, *J* = *5.0* Hz, thienyl 4-H), 7.53 (d, 2H, *J* = 8.4 Hz, benzonitrile-H), 7.76 (d, 2H, *J* = 8.4 Hz, benzonitrile-H), 7.88 (d, 1H, thienyl 3-H), 8.53 (d, 1H. thienyl 5-H), 12.65 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{14}H_8N_4OS$ (280.24.): C, 60.00, H, 2.88, N, 19.99; S, 11.42. Found C, 60.12, H, 3.13, N, 19.65; S, 11.39.

Reaction of the nitriles **12b,f,g** *and* **13d** *with hydroxylamine-O-sulfonic acid for the preparation of* **15b,d,f,g**

To a solution of 0.1 mmol of each of compound **12b,f,g** and **13d** in 10 ml ethanol, hydroxylamine-*O*-sulfonic acid (0.069 g, 0.1 mmol) and sodium acetate (0.2 mmol) was added. The mixture was heated under reflux for 1 h. The reaction mixture was then poured into water, filtered off and recrystallised from ethanol to give yellow needles of **15b,d,f,g**.

N^2-Hydroxy-3-oxo-3-phenyl-2-(p-tolylhydrazono)propanimidamide (**15b**): Yield (60 %, 1.77 g); m.p. 199–200 °C; IR (KBr): ν/cm^{-1}: 3447 (OH), 3338 and 3275 (NH_2), 3062 (NH) and 1639 (CO); MS: *m/z* = 296 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 2.45 (s, 3H, CH_3), 6.51 (br s 2H, D_2O exchangeable NH_2), 7.45 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 7.55–7.32 (m, 2H, phenyl-H), 7.60 (t, 1H, *J* = 7.6 Hz, phenyl-H), 7.94 (d, 2H, *J* = 7.6 Hz, phenyl-H), 8.08 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 10.02 (br s, 1H, OH, D_2O exchangeable). 13.79 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{16}H_{16}N_4O_2$ (296.32): C 64.85, H 5.44, N 18.91. Found C 64.63, H 5.40, N 19.12.

N^2-Hydroxy-3-oxo-2-phenylhydrazono-3-(p-tolyl) propanimidamide (**15d**): Yield (89 %, 2.5 g); m.p. 206–207 °C; IR (KBr): ν/cm^{-1}: 3445 (OH), 3340 and 3287 (NH_2), 3060 (NH) and 1642 (CO); MS: *m/z* = 296 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 2.40 (s, 3H, CH_3), 6.65 (br s 2H, D_2O exchangeable NH_2), 7.10 (t, 1H, *J* = 7.5 Hz, phenyl-H), 7.19 (d, 2H, *J* = 8.0 Hz, tolyl-H), 7.52 (d, 2H, *J* = 7.5 Hz, phenyl-H), 7.40 (t, 2H, *J* = 7.8 Hz, phenyl-H), 7.80 (d, 2H, *J* = 8.0 Hz, tolyl-H), 9.98 (br s, 1H, OH, D_2O exchangeable), 13.88 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{16}H_{16}N_4O_2$ (296.32): C 64.85, H 5.44, N 18.91. Found C 68.74, H 5.34, N 19.05.

N^2-Hydroxy-3-oxo-2-phenylhydrazono-3-(2-thienyl)-propanimidamide (**15f**): Yield (69 %, 2 g); m.p. 165–166 °C (lit.[12] m.p. 154 °C); IR (KBr): ν/cm^{-1}: 3447 (OH), 3338 and 3275 (NH_2), 3062 (NH), 1639 (CO); MS: *m/z* = 288 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 6.51 (br s, 2H, D_2O exchangeable NH_2), 7.12 (t, 1H, *J* = 7.0 Hz, phenyl-H), 7.22 (t, 1H, *J* = 5.0 Hz, thienyl 4-H), 7.35 (d, 2H, *J* = 7.0 Hz, phenyl-H), 7.44 (t, 2H, *J* = 7.0 Hz, phenyl-H), 7.99 (t, 1H, *J* = 5.0 Hz, thienyl 3-H), 8.00 (d, 1H, *J* = 5.0 Hz, thienyl 5-H), 10.34 (s, 1H, oxime-OH), 13.82 (br s, 1H, NH, D_2O exchangeable), 12.89 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{13}H_{12}N_4O_2S$ (288.26): C 54.16, H 4.20, N 19.44, S 11.10. Found C 54.45, H 4.44, N 19.44, S 11.11.

N^2-Hydroxy-3-oxo-3-(2-thienyl)-2-(p-tolylhydrazono)propanimidamide (**15 g**): Yield (79 %, 2.4 g); m.p. 159–160 °C; IR (KBr): ν/cm^{-1}: 3485 (OH), 3333 and 3273 (NH_2), 3253 (NH), and 1627 (CO); MS: *m/z* = 302 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 2.25 (s, 3H, CH_3), 6.54 (br s, 2H, NH_2), 7.23–7.30 (m, 5H, tolyl-H and thienyl 4-H), 7.97 (d, 1H, *J* = 5.0 Hz, thienyl 3-H), 8.02 (d, 1H, *J* = 5.0 Hz, thienyl 5-H), 10.34 (br s, 1H, OH, D_2O exchangeable). 13.91 (br s, 1H, NH, D_2O exchangeable). Anal. Calcd. for $C_{14}H_{14}N_4O_2S$ (302.08): C 55.61, H 4.67, N 18.53, S 10.61. Found C 55.85, H 4.41, N 18.67, S 10.71.

General procedure for the preparation of **16b,d,f,g** *and* **17f,g**

Method A: A solution of 0.1 mmol of each of compounds **15b,d** in 10 ml ethoxide was heated under reflux for 1 h. The reaction mixture was then poured into water, neutralised with HCl, filtered off and recrystallised from ethanol to give yellow needles of **16b,d** and mixture of **16f,g** along with **17f,g** that were separated and purified by flash chromatography on silica gel using chloroform/n-hexane (3: 1 v/v) as eluent.

Method B: To a solution of 0.1 mmol of each of compounds **2b,d** in 10 ml acetic acid, hydroxylamine-*O*-sulfonic acid (1.5 g) and sodium acetate (0.5 g) were added. The mixture was heated under reflux for 1 h. The reaction mixture was then poured into water, filtered off and recrystallised from ethanol to give yellow needles of **16b,d** and mixture of **16f,g** along with **17f,g** which were separated and purified by flash chromatography on silica gel using chloroform/n-hexane (3: 1 v/v) as eluent.

5-Phenyl-4-(p-tolylazo)-1,2-oxazol-3-amine (**16b**): This compound was obtained as yellow crystals from ethanol, yield (80 %, 2.2 g); m.p. 196–197 °C; IR (KBr): ν/cm^{-1}: 3341 and 3298 (NH_2), MS: *m/z* = 278 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 2.45 (s, 3H, CH_3), 6.63 (br s, 2H, NH_2), 7.40 (d, 2H, *J* = 8.0 Hz, *p*-tolyl-H), 7.59–7.66

(m, 3H, phenyl-H), 7.86 (d, 2H, *J* = 8.2 Hz, phenyl-H), 8.20 (d, 2H, *J* = 8.0 Hz, *p*-tolyl-H); ^{13}C NMR (DMSO-d_6): δ (ppm) = 167.28, 157.36, 151.29, 142.35, 132.36, 131.02, 130.30, 128.59, 127.75, 125.10, 123.30, 120.36, 22.09. Anal. Calcd. for $C_{16}H_{14}N_4O$ (278.30): C 69.05, H 5.07, N 20.13. Found C 69.20, H 5.08, N 20.36.

4-Phenylazo-(5-p-tolyl)-1,2-oxazol-3-amine (**16d**): Yield (86 %, 2.4 g); m.p. 183–184 °C; IR (KBr): ν/cm^{-1}: 3276 and 3215 (NH_2); MS: *m/z* = 278 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 2.41 (s, 3H, CH_3), 6.64 (br s, 2H, NH_2), 7.25 (d, 2H, *J* = 8.0 Hz, *p*-tolyl-H), 7.37–7.61 (m, 3H, phenyl-H), 7.94 (d, 2H, *J* = 7.5 Hz, phenyl-H), 8.09 (d, 2H, *J* = 8.0 Hz, *p*-tolyl-H); ^{13}C NMR (DMSO-d_6): δ (ppm) = 168.06, 157.21, 153.20, 142.69, 132.00, 130.91, 130.49, 128.63, 127.04, 125.10, 124.96, 119.97, 22.20. Anal. Calcd. for $C_{16}H_{14}N_4O$ (278.30): C 69.05, H 5.07, N 20.13. Found C 69.09, H 5.27, N 20.11.

4-Phenylazo-5-(2-thienyl)-1,2-oxazol-3-amine (**16f**): Yield (30 %, 0.8 g); m.p. 155–156 °C; IR (KBr): ν/cm^{-1}: 3261 and 3199 (NH_2), MS: *m/z* = 270 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 6.64 (br s, 2H, NH_2), 7.31–7.39 (m, 2H, thienyl 4-H and phenyl-H), 7.95–7.96 (m, 2H, phenyl-H), 8.03 (d, 2H, *J* = 7.2 Hz, phenyl-H), 8.05 (d, 2H, *J* = 5.0 Hz, thienyl 3-H), 8.55 (d, 1H, *J* = 5.0 Hz, thienyl 5-H); ^{13}C NMR (DMSO-d_6): δ (ppm) = 164.48, 157.30, 156.83, 153.25, 132.04, 130.48, 129.6, 129.02, 127.28, 124.05 and 119.40. Anal. Calcd. for $C_{13}H_{10}N_4OS$ (270.24): C 57.77, H 3.73, N 20.73, S 11.84. Found C 57.77, H 3.76, N 20.53, S 11.82.

5-(2-thienyl)-4-p-tolylazo-1,2-oxazol-3-amine (**16 g**): Yield (36 %, 1.0 g); m.p. 170–172 °C; IR (KBr): ν/cm^{-1}: 3270 and 3227 (NH_2); MS: *m/z* = 284 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 2.45 (s, 3H, CH_3), 6.68 (br s, 2H, NH_2), 7.26–7.30 (m, 3H, thienyl 4-H and tolyl-H), 7.50 (d, 2H, *J* = 8.2 Hz, *p*-tolyl-H), 8.05 (d, 1H, *J* = 5.0 Hz, thienyl 3-H), 8.16 (d, 1H, *J* = 5.0 Hz, thienyl 5-H). ^{13}C NMR (DMSO-d_6): δ (ppm) = 163.99, 156.92, 151.39, 138.93, 131.05, 131.02, 130.82, 129.59, 123.63, 123.35, 113.60 and 22.10. Anal. Calcd. for $C_{14}H_{12}N_4OS$ (284.27): C 59.15, H 4.26, N 19.71, S 11.26. Found C 59.12, H 4.27, N 19.46, S 11.13.

(5-Amino-2-phenyl-2H-[1,2,3]-triazol-4-yl)(2-thienyl)methanone (**17f**): Yield (55 %, 1.5 g); m.p. 166–168 °C; IR (KBr): ν/cm^{-1}: 3398 and 3287 (NH_2), 1622 (CO); MS: *m/z* = 270 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 6.54 (br s, 2H, NH_2), 7.45 (t, 1H, *J* = 5.0 Hz, thienyl 4-H), 7.50–7.53 (m, 1H, phenyl-H), 7.67 (t, 2H, *J* = 7.2 Hz, phenyl-H), 8.06 (d, 2H, *J* = 7.2 Hz, phenyl-H), 8.11 (d, 2H, *J* = 5.0 Hz, thienyl 3-H), 8.53 (d, 1H, *J* = 5.0 Hz, thienyl 5-H); ^{13}C NMR (DMSO-d_6): δ (ppm) = 178.45 (CO), 142.80, 139.71, 136.56, 135.98, 135.51, 134.61, 131.14, 130.79, 130.59 and 123.78. Anal. Calcd. for $C_{13}H_{10}N_4OS$ (270.24): C 57.77, H 3.73, N 20.73, S 11.84. Found C 57.74, H 3.65, N 20.62, S 11.82.

(5-Amino-2-p-tolyl-2H-[1,2,3]-triazol-4-yl)(2-thienyl)methanone (**17 g**): Yield (52 %, 1.47 g); m.p. 179–180 °C; IR (KBr): ν/cm^{-1}: 3274 and 3227 (NH_2) and 1622 (CO); MS: *m/z* = 284 (M^+); ^{1}H NMR (DMSO-d_6): δ (ppm) = 2.45 (s, 3H, CH_3), 6.60 (br s, 2H, NH_2), 7.34 (t, 1H, *J* = 5.0 Hz, thienyl 4-H), 7.39 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 7.82 (d, 2H, *J* = 8.4 Hz, *p*-tolyl-H), 7.95 (d, 1H, *J* = 5.0 Hz, thienyl 3-H), 8.05 (d, 1H, *J* = 5.0 Hz, thienyl 5-H). ^{13}C NMR (DMSO-d_6): δ (ppm) = 178.39 (CO), 142.87, 142.30, 137.58.35, 136.50, 135.90, 134.42.19, 131.18, 129.59,127.88, 119.35 and 21.66. Anal. Calcd. for $C_{14}H_{11}N_3OS$ (284.27): C 59.15, H 4.26, N 19.71, S 11.26. Found C 59.12, H 4.27, N 19.46, S 11.13.

Thermal gas-phase kinetic runs and data analysis

Stock solution (7 ml) was prepared by dissolving 6–10 mg of the substrate in acetonitrile as solvent to give a concentration of 1,000–2,000 ppm. Internal standard was then added, the amount of which is adjusted to give the desired peak area ratio of substrate to standard (2.5: 1). The solvent and the internal standard were selected because both are stable under the conditions of pyrolysis, and because they do not react with either substrate or product. The internal standards used in this study were chlorobenzene, 1,3-dichlorobenzene and 1,2,4-trichlorobenzene. Each mixture was filtered to ensure that a homogeneous solution is obtained.

The weight ratio of the substrate with respect to the internal standard was calculated from the ratio of the substrate peak area to the peak area of the internal standard. The kinetic rate was determined by tracing the rate of disappearance of the substrate with respect to the internal standard as follows:

An aliquot part (0.2 ml) of each solution containing the substrate and the internal standard was pipetted into the reaction tube, which was then placed in the pyrolyser for 6 minutes under non-thermal conditions. A sample was then analysed using the HPLC probe with the UV detector at wavelength of 256 nm, and the standardisation value (A_o) was then calculated. Several HPLC measurements were obtained with an accuracy of ≥ 2 %. The temperature of the pyrolysis block was then raised until approximately 10 % pyrolysis was deemed to occur over 900 s. This process was repeated after each 10–15 ºC rise in the temperature of the pyrolyser until ≥ 90 % pyrolysis occurred. The relative ratios of the integration values of the sample and the internal standard (A) at the pyrolysis temperature were then calculated. A minimum of three kinetic runs was carried out at each 10–15 ºC rise in the temperature of the pyrolyser to ensure reproducible values of (A). Treatment of the kinetic data has been detailed elswere.[23,27,28]

Analyses were conducted using a Chemical Data System (CDS) custom-made pyrolyser comprising an insulated aluminium alloy block fitted with a platinum resistance thermocouple connected to a Comark microprocessor thermometre for reactor temperature read-out. The temperature of the reactor was controlled by means of a Eurotherm 093 precision temperature regulator. HPLC analysis of kinetic runs was carried out on: (a) Waters HPLC (pump model 515, UV detector model 2487); (b) Metrohm HPLC (pump model 709 IC, SPD 10AV Shimadzo UV detector).

Product analysis

The apparatus used for this purpose was the same pyrolysis unit used for kinetic studies. Each of the substrates (0.2 g) was introduced in the reaction tube, cooled in liquid nitrogen, sealed under vacuum and placed in the pyrolyser for 900 seconds at a temperature comparable to that used for complete pyrolysis in the kinetic studies. The contents of the tube were then analysed by NMR and LC/MS and yield was determined by HPLC with reference to an authentic sample. The spectral data of the pyrolysates were compared with their reference spectra.

Flash vacuum pyrolysis (FVP)

The apparatus used was the one which has been described in recent publications.[29,30] The sample was volatilised from a tube in a Büchi Kugelrohr oven through a 30 × 2.5 cm horizontal fused quartz tube. This was heated externally by a Carbolite Eurotherm tube furnace MTF-12/38A to a temperature of 500 °C, the temperature being monitored by a Pt/Pt-13 %Rh thermocouple situated at the centre of the furnace. The products were collected in a U-shaped trap cooled in liquid nitrogen. The whole system was maintained at a pressure of 10^{-2} Torr by an Edwards Model E2M5 high capacity rotary oil pump, the pressure being measured by a Pirani gauge situated between the cold trap and the pump. Under these conditions the contact time in the hot zone was estimated to be ≅ 10 ms. The different zones of the products collected in the U-shaped trap were analysed by ^{1}H NMR, LCMS and GC-MS. Relative and percent yields were determined from ^{1}H NMR. Identity of compounds obtained were confirmed by comparison of their ^{1}H NMR with data of products separated from preparative HPLC.

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