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New efficient synthesis of trisubstituted imidazolidine-2-thiones and thiazoles via vinyliminophosphoranes

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ABSTRACT

Isothiocyanate **6**, obtained from vinyliminophosphorane **4** with CS_2, reacted with various aliphatic primary amines to afford directly the 1,4,5-trisubstituted imidazolidine-2-thiones **5**. However, the reaction of isothiocyanate **6** with aliphatic secondary amines provided 2,4,5-trisubstituted thiazoles **10** in good yields.

1. Introduction

Imidazole and its derivatives are one of the most important classes of heterocyclic compounds. Imidazolidine-2-thiones are among them of constant interest owing to the occurrence of this ring system in various biologically important compounds.[1] Some derivatives of this ring system have shown interesting biological activities and pharmacological properties, such as antihyperthyroid,[2] antitumor,[3] antibacterial,[4] antiinflammatory,[5] antiarthritic[6] and anticytokine activities.[7] Others were used as cholesterol acyltransferase (ACAT) inhibitor,[8] dopamine β-hydroxylase inhibitors,[9] α-glucosidase and α-amylase inhibitors.[10] In addition, some imidazolidine-2-thiones are applied for promoting the enantioselective Friedel–Crafts alkylation as organocatalysts.[11] Imidazolidine-2-thiones are generally prepared by condensation of α-hydroxy ketones with ammonium thiocyanate and thiourea.[12] They could be also prepared by cyclization of some acylthioureas with α-bromo ketones,[13] or by the addition reaction between amine and isothiocyanates.[14] Thiazole skeletons are also one of the most important and central building blocks in medicinal and pharmaceutical chemistry. Many thiazoles are found in a wide variety of biologically active substances, which show antioxidant, antitumor, antiinflammatory, antifungal and antibacterial activities.[15–18] Thiazole ring is also a structural motif of natural compounds, such as vitamin B_1 (thiamine), penicillin and carboxylase. Although many synthetic methods have been reported for imidazolidine-2-thiones and thiazoles, new method for preparing of the two heterocycles is still desirable.

The aza-Wittig reactions of iminophosphoranes have received increased attention in view of their utility in the synthesis of nitrogen-containing heterocyclic compounds.[19] Owning to its good stability, vinyliminophosphorane may be considered to be an equivalent of the unstable enamine. The reactions of vinyliminophosphoranes with carbon disulfide produced otherwise not easily accessible vinylisothiocyanates, which reacted further with various nucleophiles through nucleophilic addition/intramolecular cyclization to afford some heterocycles, such as 2-thioxo-imidazolidiones,[20] imidazo[2,1-*b*]-1,3,4-thiadiazol-5(6*H*)-ones[21] and aplysinopsin-type alkaloids.[22] Recently we have been interested in the synthesis of various heterocycles via aza-Wittig reaction, with the aim of evaluating their biological activities.[23] Herein we wish to report a new approach to the synthesis of trisubstituted imidazolidine-2-thiones and thiazole starting from vinyliminophosphorane in a one-pot fashion.

2. Results and discussion

Vinyl azide **3** was prepared either from the condensation of the α-azidoketone **1** with aromatic aldehydes in the presence of piperidinium acetate,[24] or from the reaction of dibromide **2** with sodium azide.[25] Further Staudinger reaction of the azide **3** with triphenylphosphine (R=Ph) or methyldiphenylphosphine (R=Me) at room temperature produced vinyliminophosphorane **4** in good yields (Scheme 1).

Initially, we selected the triphenyliminophosphorane **4a** (R=Ph), CS_2 and methylamine as the reactants (Scheme 2). After the triphenyliminophosphorane **4a** and excess CS_2 was stirred in acetonitrile at 40 °C for 24 h, methylamine was added and the mixture was stirred at room temperature. Finally imidazolidine-2-thione **5a** was directly obtained from the reaction mixture but in low yield (12%), which implies the low reactivity of triphenyliminophosphorane **4a** toward CS_2. However as more reactive methyldiphenyl

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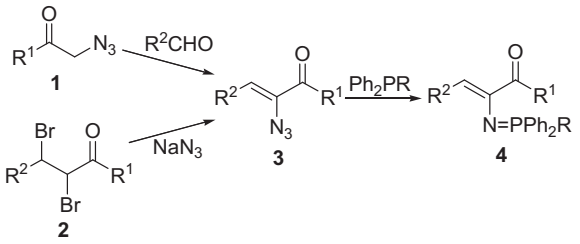
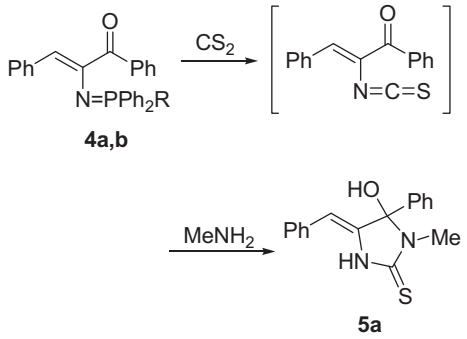


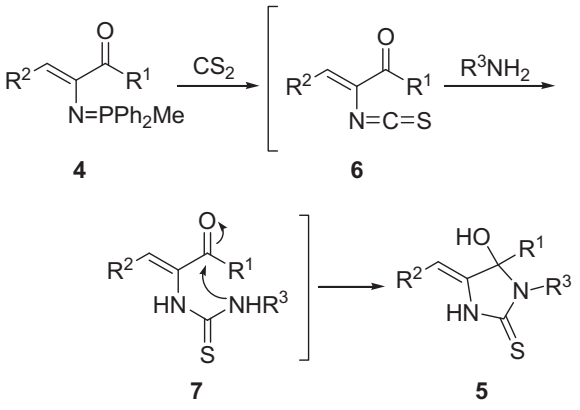
Scheme 1. Preparation of vinyliminophosphoranes **4**.



Scheme 2. Preparation of compounds **5a**.

iminophosphorane **4b** (R=Me) was used to react with CS_2, the reaction took place smoothly at 40 °C for only 4 h and the imidazolidine-2-thione **5a** was obtained in 79% yield.

With the optimized condition, various methyldiphenyl iminophosphorane **4** (R=Me), CS_2 and aliphatic primary amine were employed for the reaction (Scheme 3). The reaction yields are found to relate with R^1, R^2 and R^3 substituents (Table 1). When R^1 and R^2



Scheme 3. Preparation of imidazolidine-2-thiones **5**.

are aryl groups, the reactions proceeded smoothly to give the corresponding 1,4,5-trisubstituted imidazolidine-2-thione **5** in 79–88% yields (**5a**–**m**). However, moderate yields (46–52%) were obtained as R^1 is changed to an alkyl group (**5n** and **5o**), and no product was got in case that R^2 is an alkyl group (**5p** and **5q**). Finally, when aromatic primary amine (R^3=aryl, **5r** and **5s**) was used, no imidazolidine-2-thiones **5** was obtained probably due to the low reactivity of the aromatic primary amine. The structure of 1*H*-imidazole-2(3*H*)-thiones **5** was confirmed by their spectrum data. For example, the ^{1}H NMR spectrum of **5g** shows two singlets at 8.25 and 3.24 ppm due to the NH and OH, respectively, which can be exchanged by D_2O. The signals of =CH are found at 5.46 ppm as

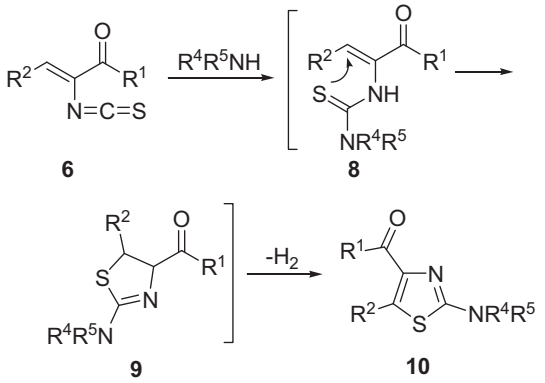
Table 1
Preparation of imidazolidine-2-thiones **5** from methyldiphenyl iminophosphorane **4** (R=Me)

	R^1	R^2	R^3	Yield[a] (%)
5a	Ph	Ph	Me	79
5b	Ph	Ph	Et	82
5c	Ph	Ph	*n*-Pr	80
5d	Ph	Ph	*n*-Bu	80
5e	Ph	Ph	*i*-Pr	84
5f	Ph	Ph	*c*-C_6H_{11}	88
5g	Ph	Ph	$PhCH_2$	86
5h	Ph	4-ClC_6H_4	*n*-Pr	84
5i	Ph	4-FC_6H_4	Et	87
5j	Ph	4-$CH_3C_6H_4$	Et	83
5k	Ph	4-$CH_3OC_6H_4$	Et	84
5l	Ph	4-$CF_3C_6H_4$	Et	86
5m	4-ClC_6H_4	Ph	*n*-Pr	82
5n	Me	Ph	$PhCH_2$	52
5o	Me	Ph	*c*-C_6H_{11}	46
5p	Ph	Et	Et	0
5q	Ph	Et	*n*-Pr	0
5r	Ph	Ph	Ph	0
5s	Me	Ph	Ph	0

[a] Isolated yields based on iminophosphorane **4** (R=Me).

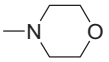
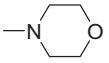
singlet. The signals of NCH_2Ph appear at 5.05 and 4.27 ppm as two doublets. The signals attributable to the Ar–Hs are found at 7.43–7.16 ppm as multiplets. The ^{13}C NMR spectrum data in **5g** showed the signals of quaternary COH carbon at 93.8 ppm but no signals of C=O carbon. The alkenyl carbon absorbs at 102.1 ppm. The MS spectrum of **5g** shows molecular ion peak at *m*/*z* 372 with 100% abundance. The formation of the imidazolidine-2-thione **5** can be rationalized in terms of an initial aza-Wittig reaction between iminophosphorane **4** and CS_2 to give the vinylisothiocyanate **6** (Scheme 3). Further reaction of **6** with amine produces thiourea **7** as intermediate, then an intramolecular nucleophilic addition of the thiourea to carbonyl group takes place to give the imidazolidine-2-thione **5**. The failure in preparation of compounds **5p** and **5q** might be due to polymerization of the intermediate vinylisothiocyanate **6p** and **6q**, in which R^2 is a relatively electrodonating ethyl group. In these cases, vinylisothiocyanate **6p** and **6q** might produce but polymerized quickly and were not detected by TLC detection.

It is interesting to note that thiazoles **10** were obtained instead when isothiocyanates **6** were allowed to react with aliphatic secondary amines (Scheme 4, Table 2). The reaction yields are also found to relate with R^1 and R^2 substituents (Table 2). When R^1 and R^2 are aryl groups, the reactions occurred smoothly to produce the thiazoles **10** in 80–90% yields (**10a**–**i**). However, moderate yields (40–55%) were obtained as R^1 is changed to an alkyl group (**10j** and



Scheme 4. Preparation of thiazoles **10**.

Table 2
Preparation of thiazoles **10**

	R^1	R^2	NR^4R^5	Yield[a] (%)
10a	Ph	Ph	NEt_2	88
10b	Ph	Ph		85
10c	Ph	Ph		89
10d	Ph	4-FC_6H_4		81
10e	Ph	4-$CH_3C_6H_4$	$N(n\text{-}Pr)_2$	80
10f	Ph	4-$CH_3OC_6H_4$		86
10g	Ph	4-$CF_3C_6H_4$		90
10h	Ph	4-$CF_3C_6H_4$	$N(i\text{-}Pr)_2$	86
10i	4-ClC_6H_4	Ph		84
10j	Me	Ph		55
10k	Me	Ph	$N(i\text{-}Pr)_2$	40
10l	Ph	Et	NEt_2	0
10m	Ph	Ph	NPh_2	0

[a] Isolated yields based on iminophosphorane **4** (R=Me).

10k). No product was created in case that R^2 is an alkyl group (**10l**) or aromatic primary amines (R^4, R^5=aryl) were utilized (**10m**). It is deduced that higher reaction temperature is needed for aromatic amine, but the isothiocyanate intermediate **6** might be unstable under higher temperature. The structure of thiazoles **10** was confirmed by their spectrum data. For example, the ^1H NMR spectrum of **10a** shows quartet at 3.51 and triplet at 1.27 ppm due to the NCH_2CH_3, respectively. The signals attributable to the Ar–Hs are found at 8.00–7.17 ppm as multiplet. The ^{13}C NMR spectrum data in **10a** showed the signals of C=O carbon at 191.1 ppm. The MS spectrum of **10a** shows molecular ion peak at *m*/*z* 336 with 93% abundance. Furthermore a single crystal of thiazole **10b** was obtained from the CH_2Cl_2 solution of **10b**, and X-ray structure analysis verified the proposed structure (Fig. 1). The formation of thiazoles **10** can be rationalized in terms of an addition reaction between isothiocyanates **6** and aliphatic secondary amines to give thiourea intermediate **8**. Further intramolecular Michael addition reaction (*S*-attack) takes place to produce dihydrothiazole intermediate **9**, which undergoes dehydrogenating aromatization to give the thiazole **10** by air oxidation under the heating condition. The above one-pot reaction provides a new efficient synthesis of thiazoles under mild reaction condition. The reasons for the above different selectivity are not yet very clear, however, it is deduced that the intermediate dihydrothiazole **9** might be stable sufficiently and easier to form to produce thiazole **10** after subsequent dehydrogenating aromatization.

3. Conclusion

We have developed an efficient one-pot synthesis of trisubstituted imidazolidine-2-thiones **5** and thiazoles **10** from vinyliminophosphoranes **3** via different cyclization reaction. Due to the convenient practical procedure, the mild reaction condition, the good yields, and easily accessible starting material, we think that this new synthetic approach discussed here has potential in the synthesis of many biologically and pharmaceutically active imidazolidine-2-thione and thiazole derivatives.

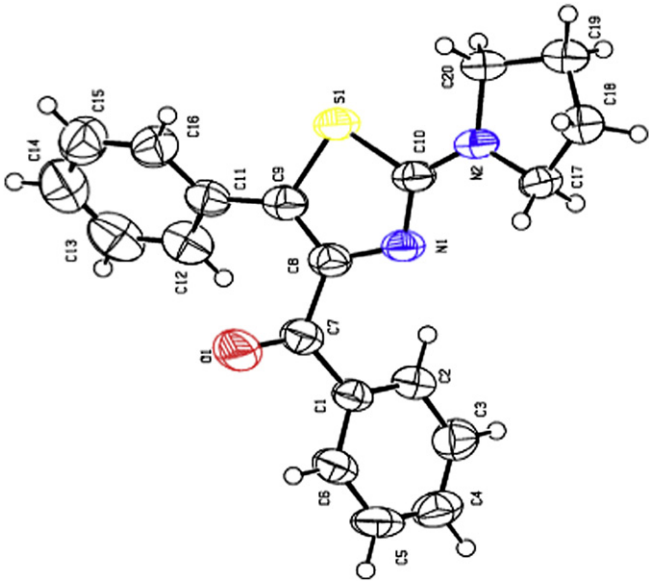


Fig. 1. ORTEP diagram of the crystal structure of **10b** (30% thermal ellipsoids).

4. Experimental

4.1. General

Melting points were determined using a X-4 model apparatus and were uncorrected. MS were measured on a Finnigan Trace MS spectrometer. IR were recorded on a PE-983 infrared spectrometer as KBr pellets with absorption in cm^{-1}. NMR were recorded in $CDCl_3$ or DMSO-d_6 on a Varian Mercury 600 spectrometer and resonances relative to TMS. Elementary analyses were taken on a Vario EL III elementary analysis instrument. The X-ray diffraction data were collected on a *Bruker SMART AXS CCD* diffractometer, MoKα, 2θ=1.86–27.50°.

4.2. Synthesis of imidazolidine-2-thione 5

*4.2.1. 4-Benzylidene-5-hydroxy-1-methyl-5-phenyl imidazolidine-2-thione (**5a**)* A solution of methyldiphenylphosphine (0.20 g, 1 mmol) in dry CH_2Cl_2 (5 mL) was added dropwise to a well-stirred solution of vinyl azides **3a** (Ar^1=Ar^2=Ph, 0.25 g, 1 mmol) in CH_2Cl_2 (5 mL) at room temperature. After the stirring was continued for 2 h, the solvent was evaporated under reduced pressure and the residue was added dry CH_3CN (5 mL) and excess carbon disulfide (5 mL). After the reaction mixture was stirred for 4 h at 40 °C, the solvent was removed under reduced pressure to give isothiocyanate **6**, which was used directly without further purification. To a solution of crude **6** in methylene chloride (10 mL) was added aqueous methylamine solution (0.10 g, 40%, 1.3 mmol). The mixture was stirred for 6–7 h at room temperature and the solvent was removed under reduced pressure, the residue was recrystallized from methylene chloride/petroleum ether to give imidazolidine-2-thione **5a** as white solid (0.23 g, 79%). Mp: 199–200 °C. ^1H NMR (DMSO-d_6, 600 MHz): δ 10.64 (s, 1H, NH), 7.50–7.12 (m, 10H, Ar–H), 5.25 (s, 1H, =CH), 3.35 (s, 1H, OH), 2.80 (s, 3H, CH_3). ^{13}C NMR (DMSO-d_6, 150 MHz): δ 178.7, 142.2, 140.9, 134.7, 128.6, 128.4, 127.8, 126.0, 125.2, 101.9, 93.1, 27.9. MS *m*/*z* (%): 296 (M^+, 100), 279 (34),

219 (50), 118 (50), 91 (27). IR (KBr): ν=3447, 3190, 1503, 1429, 1264, 1101, 1051 cm^{-1}. Anal. Calcd for $C_{17}H_{16}N_2OS$: C, 68.89; H, 5.44; N, 9.45; S, 10.82. Found: C, 68.97; H, 5.29; N, 9.61; S, 10.73.

*4.2.2. 4-Benzylidene-1-ethyl-5-hydroxy-5-phenyl imidazolidine-2-thione (**5b**)* Operation as above with ethylamine solution (0.09 g, 1.3 mmol), compound **5b** (0.25 g, 82%) was also isolated as white solid. Mp: 187–189 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 8.10 (s, 1H, NH), 7.51–7.19 (m, 10H, Ar–H), 5.50 (s, 1H, =CH), 3.73–3.67 (m, 1H, NCH), 3.50 (s, 1H, OH), 3.33–3.27 (m, 1H, NCH), 1.08 (t, J=7.2 Hz, 3H, CH_3). ^{13}C NMR (DMSO-d_6, 150 MHz): δ 178.1, 142.5, 141.6, 134.8, 128.4, 128.3, 127.8, 126.0, 125.5, 101.6, 93.5, 36.9, 14.2. MS: m/z (%): 310 (M^+, 100), 233 (26), 205 (26), 118 (37), 105 (51). IR (KBr): ν=3515, 3184, 1494, 1431, 1245, 1115, 1055 cm^{-1}. Anal. Calcd for $C_{18}H_{18}N_2OS$: C, 69.65; H, 5.84; N, 9.02; S, 10.33. Found: C, 69.43; H, 5.96; N, 9.21; S, 10.19.

*4.2.3. 4-Benzylidene-5-hydroxy-5-phenyl-1-propyl imidazolidine-2-thione (**5c**)* Operation as above with *n*-propylamine (0.08 g, 1.3 mmol), compound **5c** (0.25 g, 80%) was also isolated as white solid. Mp: 134–136 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 8.12 (s, 1H, NH), 7.50–7.19 (m, 10H, Ar–H), 5.50 (s, 1H, =CH), 3.62–3.57 (m, 1H, NCH), 3.35 (s, 1H, OH), 3.13–3.08 (m, 1H, NCH), 1.65–1.44 (m, 2H, CH_2), 0.78 (t, J=7.2 Hz, 3H, CH_3). ^{13}C NMR ($CDCl_3$, 150 MHz): δ 178.0, 141.4, 139.1, 134.7, 129.0, 128.5, 127.4, 127.1, 125.9, 103.3, 94.1, 45.3, 22.5, 11.3. MS: m/z (%): 324 (M^+, 100), 247 (15), 219 (22), 160 (12), 118 (32), 105 (70). IR (KBr): ν=3446, 3146, 1565, 1431, 1232, 1120, 1070 cm^{-1}. Anal. Calcd for $C_{19}H_{20}N_2OS$: C, 70.34; H, 6.21; N, 8.63; S, 9.88. Found: C, 70.06; H, 6.33; N, 8.82; S, 9.69.

*4.2.4. 4-Benzylidene-1-butyl-5-hydroxy-5-phenyl imidazolidine-2-thione (**5d**)* Operation as above with *n*-butylamine (0.10 g, 1.3 mmol), compound **5d** (0.27 g, 80%) was also isolated as white solid. Mp: 146–148 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 8.12 (s, 1H, NH), 7.50–7.16 (m, 10H, Ar–H), 5.50 (s, 1H, =CH), 3.67–3.62 (m, 1H, NCH), 3.27 (s, 1H, OH), 3.17–3.12 (m, 1H, NCH), 1.60–1.19 (m, 4H, CH_2CH_2), 0.82 (t, J=7.2 Hz, 3H, CH_3). ^{13}C NMR ($CDCl_3$, 150 MHz): δ 177.9, 141.4, 139.0, 134.6, 129.0, 128.9, 128.5, 127.4, 127.3, 127.0, 125.9, 103.3, 103.2, 94.2, 43.1, 31.0, 20.2, 13.6. MS: m/z (%) 338 (M^+, 100), 233 (22), 194 (12), 149 (25), 118 (32), 105 (56). IR (KBr): ν=3439, 3141, 1502, 1413, 1257, 1121, 1070 cm^{-1}. Anal. Calcd for $C_{20}H_{22}N_2OS$: C, 70.97; H, 6.55; N, 8.28, S, 9.47. Found: C, 71.06; H, 6.38; N, 8.44; S, 9.61.

*4.2.5. 4-Benzylidene-5-hydroxy-1-isopropyl-5-phenyl imidazolidine-2-thione (**5e**)* Operation as above with isopropylamine (0.08 g, 1.3 mmol), compound **5e** (0.27 g, 84%) was also isolated as white solid. Mp: 183–185 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 8.03 (s, 1H, NH), 7.54–7.16 (m, 10H, Ar–H), 5.37 (s, 1H, =CH), 4.11–4.07 (m, 1H, NCH), 3.21 (s, 1H, OH), 1.35 (d, J=7.2 Hz, 3H, CH_3), 1.32 (d, J=7.2 Hz, 3H, CH_3). ^{13}C NMR (DMSO-d_6, 150 MHz): δ 177.3, 142.9, 142.1, 134.9, 128.4, 128.3, 128.2, 127.8, 127.5, 125.9, 125.5, 125.3, 100.9, 94.4, 46.6, 20.3. MS: m/z (%) 324 (M^+, 100), 291 (27), 219 (21), 195 (14), 118 (39), 105 (66). IR (KBr): ν=3442, 3138, 1501, 1413, 1246, 1121, 1061 cm^{-1}. Anal. Calcd for $C_{19}H_{20}N_2OS$: C, 70.34; H, 6.21; N, 8.63; S, 9.88. Found: C, 70.38; H, 6.34; N, 8.76; S, 9.97.

*4.2.6. 4-Benzylideney-1-cyclohexyl-5-hydroxy-5-phenyl imidazolidine-2-thione (**5f**)* Operation as above with cyclohexylamine (0.12 g, 1.3 mmol), compound **5f** (0.27 g, 84%) was also isolated as white solid. Mp: 184–185 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 8.04 (s, 1H, NH), 7.53–7.16 (m, 10H, Ar–H), 5.36 (s, 1H, =CH), 3.78 (s, 1H, OH), 3.30–3.20 (m, 1H, NCH), 2.29–1.04 (m, 10H, $(CH_2)_5$). ^{13}C NMR (DMSO-d_6, 150 MHz): δ 177.5, 142.8, 142.4, 142.4, 134.9, 128.3, 128.2, 128.1, 127.8, 127.6, 125.8, 125.4, 100.8, 94.3, 55.2, 30.1, 29.7, 25.9, 25.8, 25.0. MS: m/z (%) 364 (M^+, 100), 331 (26), 259 (23), 205 (18), 118 (37), 105 (59). IR (KBr): ν=3345, 2928, 1483, 1416, 1239, 1121, 1062 cm^{-1}. Anal. Calcd for $C_{22}H_{24}N_2OS$: C, 72.49; H, 6.64; N, 7.69; S, 8.80. Found: C, 72.71; H, 6.78; N, 7.77; S, 8.59.

*4.2.7. 1-Benzyl-4-benzylideney-5-hydroxy-5-phenyl imidazolidine-2-thione (**5g**)* Operation as above with benzylamine (0.14 g, 1.3 mmol), compound **5g** (0.32 g, 86%) was also isolated as white solid. Mp: 182–184 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 8.25 (s, 1H, NH), 7.43–7.16 (m, 15H, Ar–H), 5.46 (s, 1H, =CH), 5.05 (d, J=15.0 Hz, 1H, PhCHN), 4.27 (d, J=15.6 Hz, 1H, PhCHN), 3.24 (s, 1H, OH). ^{13}C NMR (DMSO-d_6, 150 MHz): δ 179.6, 142.2, 142.1, 141.1, 141.0, 137.9, 134.7, 128.4, 128.3, 127.9, 127.8, 127.6, 126.4, 126.1, 125.6, 102.1, 93.8, 45.3. MS: m/z (%) 372 (M^+, 100), 339 (26), 267 (23), 178 (18), 118 (37), 105 (59). IR (KBr): ν=3400, 3147, 1487, 1412, 1231, 1137, 1059 cm^{-1}. Anal. Calcd for $C_{23}H_{20}N_2OS$: C, 74.16; H, 5.41; N, 7.52; S, 8.61. Found: C, 74.11; H, 5.53; N, 7.29; S, 8.72.

*4.2.8. 4-(4-Chlorobenzylidene)-5-hydroxy-5-phenyl-1-propylimidazolidine-2-thione (**5h**)* Operation as above with *n*-propylamine (0.08 g, 1.3 mmol), compound **5h** (0.30 g, 84%) was also isolated as white solid. Mp: 180–181 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 8.22 (s, 1H, NH), 7.48–7.13 (m, 9H, Ar–H), 5.43 (s, 1H, =CH), 3.71 (s, 1H, OH), 3.58–3.54 (m, 1H, NCH), 3.12–3.07 (m, 1H, NCH), 1.62–1.43 (m, 2H, CH_2), 0.76 (t, J=7.2 Hz, 3H, CH_3). ^{13}C NMR ($CDCl_3$, 150 MHz): δ 177.9, 141.8, 138.9, 133.1, 132.6, 129.1, 129.0, 128.6, 125.8, 102.1, 94.1, 44.9, 22.2, 11.4. MS: m/z (%) 358 (M^+, 100), 253 (27), 247 (19), 152 (38), 125 (18), 105 (85). IR (KBr): ν=3442, 3129, 1499, 1417, 1240, 1118, 1063 cm^{-1}. Anal. Calcd for $C_{19}H_{19}ClN_2OS$: C, 63.59; H, 5.34; N, 7.81; S, 8.93. Found: C, 63.69; H, 5.06; N, 7.70; S, 8.95.

*4.2.9. 1-Ethyl-4-(4-fluorobenzylidene)-5-hydroxy-5-phenylimidazolidine-2-thione (**5i**)* Operation as above with ethylamine solution (0.09 g, 1.3 mmol), compound **5i** (0.28 g, 87%) was also isolated as white solid. Mp: 178–180 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 8.15 (s, 1H, NH), 7.50–7.00 (m, 9H, Ar–H), 5.45 (s, 1H, =CH), 3.71–3.65 (m, 1H, NCH), 3.57 (s, 1H, OH), 3.33–3.27 (m, 1H, NCH), 1.07 (t, J=7.2 Hz, 3H, CH_3). ^{13}C NMR (DMSO-d_6, 150 MHz): δ 178.1, 161.2, 159.6, 142.3, 141.5, 131.3, 130.8, 129.8, 128.4, 125.5, 115.2, 115.1, 100.5, 93.5, 36.9, 14.2. MS: m/z (%) 328 (M^+, 100), 223 (15), 213 (19), 136 (30), 105 (56). IR (KBr): ν=3322, 3221, 1509, 1424, 1246, 1117, 1058 cm^{-1}. Anal. Calcd for $C_{18}H_{17}FN_2OS$: C, 65.83; H, 5.22; N, 8.53; S, 9.76. Found: C, 65.52; H, 5.35; N, 8.74; S, 9.59.

*4.2.10. 1-Ethyl-5-hydroxy-4-(4-methylbenzylidene)-5-phenylimidazolidine-2-thione (**5j**)* Operation as above with ethylamine aqueous solution (0.09 g, 1.3 mmol), compound **5j** (0.26 g, 83%) was also isolated as white solid. Mp: 187–188 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 8.10 (s, 1H, NH), 7.50–7.08 (m, 9H, Ar–H), 5.46 (s, 1H, =CH), 3.72–3.68 (m, 1H, NCH), 3.39 (s, 1H, OH), 3.31–3.28 (m, 1H, NCH), 2.32 (s, 3H, CH_3), 1.08 (t, J=7.2 Hz, 3H, CH_3). ^{13}C NMR (DMSO-d_6, 150 MHz): δ 178.0, 141.6, 135.2, 131.9, 129.0, 128.4, 128.2, 127.9, 127.8, 125.4, 101.7, 93.5, 36.9, 20.8, 14.2. MS: m/z (%) 324 (M^+, 100), 307 (11), 233 (15), 219 (25), 132 (29), 105 (72). IR (KBr): ν=3377, 3135, 1515, 1403, 1242, 1115, 1063 cm^{-1}. Anal. Calcd for $C_{19}H_{20}N_2OS$: C, 70.34; H, 6.21; N, 8.63; S, 9.88. Found: C, 70.47; H, 6.05; N, 8.47; S, 9.93.

*4.2.11. 1-Ethyl-5-hydroxy-4-(4-methoxybenzylidene)-5-phenylimidazolidine-2-thione (**5k**)* Operation as above with ethylamine solution (0.09 g, 1.3 mmol), compound **5k** (0.28 g, 84%) was also isolated as white solid. Mp: 165–166 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 8.16 (s, 1H, NH), 7.50–6.84 (m, 9H, Ar–H), 5.42 (s, 1H, =CH), 3.79 (s, 3H, OCH_3), 3.71–3.66 (m, 2H, NCH, and OH), 3.32–3.29 (m, 1H, NCH), 1.06 (t, J=7.2 Hz, 3H, CH_3). ^{13}C NMR (DMSO-d_6, 150 MHz): δ 177.9, 157.5, 141.8, 140.6, 129.2, 128.4, 128.3, 127.4, 125.5, 113.8, 113.7,

113.7, 101.6, 93.5, 55.0, 36.8, 14.3. MS: *m*/*z* (%) 340 (M^+, 100), 323 (26), 235 (19), 148 (24), 121 (53), 105 (75). IR (KBr): ν=3317, 3197, 1513, 1408, 1252, 1113, 1053 cm^{-1}. Anal. Calcd for $C_{19}H_{20}N_2O_2S$: C, 67.03; H, 5.92; N, 8.23; S, 9.42. Found: C, 67.29; H, 5.68; N, 8.07; S, 9.47.

*4.2.12. 1-Ethyl-5-hydroxy-5-phenyl-4-(4-trifluoro benzylidene)imidazolidine-2-thione (**5l**)* Operation as above with ethylamine solution (0.09 g, 1.3 mmol), compound **5l** (0.33 g, 86%) was also isolated as white solid. Mp: 185–187 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 8.38 (s, 1H, NH), 7.57–7.30 (m, 9H, Ar–H), 5.49 (s, 1H, =CH), 3.85 (s, 1H, OH), 3.68–3.63 (m, 1H, NCH), 3.33–3.27 (m, 1H, NCH), 1.04 (t, J=7.2 Hz, 3H, CH_3). ^{13}C NMR (DMSO-d_6, 150 MHz): δ 178.3, 145.1, 141.2, 139.1, 128.5, 128.3, 126.0, 125.7, 125.5, 125.3, 125.1, 123.5, 99.8, 93.8, 37.0, 14.1. MS: *m*/*z* (%) 378 (M^+, 100), 273 (28), 233 (25), 186 (28), 159 (13), 105 (66). IR (KBr): ν=3387, 3131, 1494, 1420, 1246, 1118, 1067 cm^{-1}. Anal. Calcd for $C_{19}H_{17}F_3N_2OS$: C, 60.31; H, 4.53; N, 7.40; S, 8.47. Found: C, 60.43; H, 4.77; N, 7.55; S, 8.66.

*4.2.13. 1-Benzyl-4-benzylidene-5-(4-chlorophenyl)-5-hydroxyimidazolidine-2-thione (**5m**)* Operation as above with benzylamine (0.14 g, 1.3 mmol), compound **5m** (0.33 g, 82%) was also isolated as white solid. Mp: 190–191 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 8.27 (s, 1H, NH), 7.35–7.16 (m, 14H, Ar–H), 5.44 (s, 1H, =CH), 4.96 (d, J=15.0 Hz, 1H, PhCHN), 4.37 (d, J=15.6 Hz, 1H, PhCHN), 3.32 (s, 1H, OH). ^{13}C NMR (DMSO-d_6, 150 MHz): δ 179.6, 141.8, 141.7, 140.0, 137.8, 134.6, 132.9, 128.3, 128.1, 128.0, 127.8, 127.7, 127.6, 126.4, 126.2, 102.3, 93.2, 45.1. MS: *m*/*z* (%) 406 (M^+, 50), 373 (11), 267 (43), 139 (47), 118 (25), 106 (41). IR (KBr): ν=3294, 3193, 1478, 1409, 1230, 1133, 1070 cm^{-1}. Anal. Calcd for $C_{23}H_{19}ClN_2OS$: C, 67.89; H, 4.71; N, 6.88; S, 7.88. Found: C, 68.03; H, 4.70; N, 6.69; S, 7.97.

*4.2.14. 1-Benzyl-4-benzylidene-5-hydroxy-5-methyl imidazolidine-2-thione (**5n**)* Operation as above with benzylamine (0.14 g, 1.3 mmol), compound **5n** (0.16 g, 52%) was also isolated as white solid. Mp: 168–170 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 8.12 (s, 1H, NH), 7.43–7.26 (m, 10H, Ar–H), 5.77 (s, 1H, =CH), 5.11 (d, J=15.6 Hz, 1H, PhCHN), 4.83 (d, J=15.6 Hz, 1H, PhCHN), 2.79 (s, 1H, OH), 1.51 (s, 3H, CH_3). ^{13}C NMR (DMSO-d_6, 150 MHz): δ 179.1, 141.3, 138.8, 134.9, 128.8, 128.3, 128.0, 127.9, 127.2, 127.1, 126.6, 125.9, 99.9, 91.0, 43.9, 27.2. MS: *m*/*z* (%) 310 (M^+, 26), 292 (22), 201 (22), 91 (100). IR (KBr): ν=3442, 3197, 1502, 1414, 1237, 1124 cm^{-1}. Anal. Calcd for $C_{18}H_{18}N_2OS$: C, 69.65; H, 5.84; N, 9.02; S, 10.33. Found: C, 69.72; H, 5.93; N, 9.19; S, 10.06.

*4.2.15. 4-Benzylidene-1-cyclohexyl-5-hydroxy-5-methyl imidazolidine-2-thione (**5o**)* Operation as above with cyclohexylamine (0.13 g, 1.3 mmol), compound **5o** (0.14 g, 46%) was also isolated as light yellow solid. Mp: 165–167 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 7.94 (s, 1H, NH), 7.37–7.23 (m, 5H, Ar–H), 5.68 (s, 1H, =CH), 3.94–3.84 (m, 1H, NCH), 2.84 (s, 1H, OH), 2.55–1.21 (m, 13H, $(CH_2)_5$, CH_3). ^{13}C NMR (DMSO-d_6, 150 MHz): δ 176.4, 141.7, 135.2, 128.3, 127.8, 125.6, 98.5, 92.5, 54.0, 29.7, 27.4, 26.0, 25.1. MS: *m*/*z* (%) 302 (M^+, 34), 284 (100), 202 (85), 144 (32), 128 (18), 98 (23). IR (KBr): ν=3446, 3272, 1499, 1414, 1258, 1143, 1077 cm^{-1}. Anal. Calcd for $C_{17}H_{22}N_2OS$: C, 67.51; H, 7.33; N, 9.26; S, 10.60. Found: C, 67.73; H, 7.47; N, 9.36; S, 10.41.

4.3. Synthesis of thiazoles 10

*4.3.1. (2-(Diethylamino)-5-phenylthiazol-4-yl)(phenyl) methanone (**10a**)* To a solution of vinylisothiocyanate **6** prepared above in CH_3CN (10 mL) was added diethylamine (0.10 g, 1.3 mmol). The mixture was stirred for 3 h at room temperature and then refluxed for 4 h. The solvent was removed under reduced pressure and the residue was chromatographed on a silica gel column, eluting with petroleum ether/ethyl acetate (6:1) to afford the thiazole **10a** (0.29 g, 88%) as yellow solid. Mp: 61–63 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 7.99 (d, J=7.8 Hz, 2H, Ar–H), 7.47–7.17 (m, 8H, Ar–H), 3.51 (q, J=7.2 Hz, 4H, $2CH_2$), 1.26 (t, J=7.2 Hz, 6H, $2CH_3$). ^{13}C NMR ($CDCl_3$, 150 MHz): δ 191.1, 166.4, 144.5, 137.2, 132.7, 131.3, 130.3, 129.8, 128.8, 128.7, 128.5, 128.2, 127.8, 127.4, 45.3, 12.5. MS: *m*/*z* (%) 336 (M^+, 93), 307 (39), 293 (66), 215 (29), 121 (24), 105 (100). IR (KBr): ν=1663, 1547, 1448, 1330, 1218, 1103, 1075 cm^{-1}. Anal. Calcd for $C_{20}H_{20}N_2OS$: C, 71.40; H, 5.99; N, 8.33; S, 9.53. Found: C, 71.61; H, 6.12; N, 8.21; S, 9.67.

*4.3.2. Phenyl(5-phenyl-2-(pyrrolidin-1-yl)thiazol-4-yl) methanone (**10b**)* Operation as above with pyrrolidine (0.12 g, 1.3 mmol), compound **10b** (0.28 g, 85%) was also isolated as yellow crystal. Mp: 123–124 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 7.95 (d, J=7.2 Hz, 2H, Ar–H), 7.45–7.14 (m, 8H, Ar–H), 3.54–3.46 (m, 4H, $2CH_2N$), 2.08–2.02 (m, 4H, $2CH_2$). ^{13}C NMR ($CDCl_3$, 150 MHz): δ 191.2, 164.7, 144.8, 136.9, 132.6, 131.3, 130.1, 129.5, 128.6, 128.1, 127.8, 127.3, 49.4, 25.5. MS: *m*/*z* (%) 334 (M^+, 100), 305 (28), 279 (11), 263 (15), 121 (19), 105 (44). IR (KBr): ν=1652, 1555, 1482, 1324, 1212, 1123, 1073 cm^{-1}. Anal. Calcd for $C_{20}H_{18}N_2OS$: C, 71.83; H, 5.42; N, 8.38; S, 9.59. Found: C, 71.96; H, 5.59; N, 8.16; S, 9.39.

*4.3.3. (2-Morpholino-5-phenylthiazol-4-yl)(phenyl) methanone (**10c**)* Operation as above with morpholine (0.11 g, 1.3 mmol), compound **10c** (0.31 g, 89%) was also isolated as yellow solid. Mp: 161–163 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 7.94 (d, J=7.8 Hz, 2H, Ar–H), 7.48–7.21 (m, 8H, Ar–H), 3.83 (t, J=4.8 Hz, 4H, $2CH_2O$), 3.52 (t, J=4.8 Hz, 4H, $2CH_2N$). ^{13}C NMR ($CDCl_3$, 150 MHz): δ 190.7, 1168.4, 144.3, 137.0, 132.8, 132.0, 130.9, 130.3, 129.0, 128.4, 127.9, 66.0, 48.3. MS: *m*/*z* (%) 350 (M^+, 100), 305 (12), 293 (38), 215 (14), 121 (11), 105 (47). IR (KBr): ν=1655, 1511, 1451, 1326, 1214, 1116, 1071 cm^{-1}. Anal. Calcd for $C_{20}H_{18}N_2O_2S$: C, 68.55; H, 5.18; N, 7.99; S, 9.15. Found: C, 68.29; H, 5.39; N, 8.03; S, 9.01.

*4.3.4. (5-(4-Fluorophenyl)-2-morpholinothiazol-4-yl)(phenyl) methanone (**10d**)* Operation as above with morpholine (0.11 g, 1.3 mmol), compound **10d** (0.29 g, 81%) was also isolated as yellow solid. Mp: 119–120 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 7.94 (d, J=7.2 Hz, 2H, Ar–H), 7.50–6.93 (m, 7H, Ar–H), 3.83 (t, J=4.8 Hz, 4H, $2CH_2O$), 3.51 (t, J=4.8 Hz, 4H, $2CH_2N$). ^{13}C NMR ($CDCl_3$, 150 MHz): δ 190.3, 168.2, 163.2, 161.5, 144.4, 137.0, 132.9, 131.2, 131.0, 130.9, 130.3, 128.0, 126.9, 115.5, 115.3, 66.0, 48.3. MS: *m*/*z* (%) 368 (M^+, 100), 311 (33), 281 (14), 233 (19), 139 (14), 105 (50). IR (KBr): ν=1654, 1536, 1448, 1325, 1233, 1120, 1072 cm^{-1}. Anal. Calcd for $C_{20}H_{17}FN_2O_2S$: C, 65.20; H, 4.65; N, 7.60; S, 8.70. Found: C, 65.34; H, 4.77; N, 7.56; S, 8.48.

*4.3.5. (2-(Dipropylamino)-5-p-tolylthiazol-4-yl)(phenyl) methanone (**10e**)* Operation as above with dipropylamine (0.13 g, 1.3 mmol), compound **10e** (0.29 g, 81%) was also isolated as yellow solid. Mp: 45–47 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 8.01 (d, J=7.8 Hz, 2H, Ar–H), 7.48–7.04 (m, 7H, Ar–H), 3.39 (t, J=7.2 Hz, 4H, $2CH_2N$), 2.28 (s, 3H, CH_3), 1.72–1.69 (m, 4H, $2CH_2$), 0.94 (t, J=7.2 Hz, 6H, $2CH_3$). ^{13}C NMR ($CDCl_3$, 150 MHz): δ 190.8, 166.7, 144.0, 137.4, 132.5, 130.6, 130.4, 128.9, 128.8, 128.4, 127.7, 124.9, 53.0, 20.6, 11.3. MS: *m*/*z* (%) 378 (M^+, 51), 349 (13), 307 (100), 229 (27), 135 (10), 105 (53). IR (KBr): ν=1661, 1544, 1449, 1329, 1216, 1105, 1017 cm^{-1}. Anal. Calcd for $C_{23}H_{26}N_2OS$: C, 72.98; H, 6.92; N, 7.40; S, 8.47. Found: C, 73.11; H, 6.68; N, 7.53; S, 8.21.

*4.3.6. (5-(4-Methoxyphenyl)-2-(pyrrolidin-1-yl)thiazol-4-yl)(phenyl) methanone (**10f**)* Operation as above with pyrrolidine (0.12 g, 1.3 mmol), compound **10f** (0.31 g, 86%) was also isolated as yellow solid. Mp: 118–120 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 7.96

(d, J=7.8 Hz, 2H, Ar–H), 7.45–6.73 (m, 7H, Ar–H), 3.73 (s, 3H, CH_3), 3.50 (t, J=6.6 Hz, 4H, $2CH_2N$), 2.04 (t, J=6.6 Hz, 4H, $2CH_2$). ^{13}C NMR ($CDCl_3$, 150 MHz): δ 191.0, 164.1, 158.8, 144.0, 137.1, 132.5, 130.2, 130.1, 130.0, 127.7, 123.6, 113.5, 54.9, 49.3, 25.4. MS: m/z (%) 364 (M^+, 100), 335 (13), 293 (10), 182 (8), 151 (13), 105 (47). IR (KBr): ν=1650, 1550, 1460, 1326, 1210, 1113, 1072 cm^{-1}. Anal. Calcd for $C_{21}H_{20}N_2O_2S$: C, 69.20; H, 5.53; N, 7.69; S, 8.80. Found: C, 69.02; H, 5.67; N, 7.82; S, 8.56.

*4.3.7. Phenyl(2-(piperidin-1-yl)-5-(4-(trifluoromethyl) phenyl)thiazol-4-yl)methanone (**10g**)* Operation as above with piperidine (0.11 g, 1.3 mmol), compound **10g** (0.35 g, 90%) was also isolated as yellow oil. ^1H NMR ($CDCl_3$, 600 MHz): δ 8.00 (d, J=7.2 Hz, 2H, Ar–H), 7.50–7.36 (m, 7H, Ar–H), 3.49 (t, J=5.4 Hz, 4H, $2CH_2N$), 1.68–1.56 (m, 6H, $3CH_2$). ^{13}C NMR ($CDCl_3$, 150 MHz): δ 190.7, 168.7, 145.6, 136.9, 135.0, 133.0, 130.3, 128.9, 128.4, 128.0, 125.2, 65.4, 49.4, 24.9. MS: m/z (%) 416 (M^+, 100), 387 (31), 360 (28), 282 (11), 189 (18), 105 (92). IR (KBr): ν=1658, 1535, 1446, 1323, 1220, 1121, 1068 cm^{-1}. Anal. Calcd for $C_{22}H_{19}F_3N_2OS$: C, 63.45; H, 4.60; N, 6.73; S, 7.70. Found: C, 63.59; H, 4.73; N, 6.57; S, 7.42.

*4.3.8. (2-(Diisopropylamino)-5-(4-(trifluoromethyl)phenyl)thiazol-4-yl)(phenyl)methanone (**10h**)* Operation as above with diisopropylamine (0.13 g, 1.3 mmol), compound **10h** (0.37 g, 86%) was also isolated as yellow solid. Mp: 52–54 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 8.04 (d, J=8.4 Hz, 2H, Ar–H), 7.54–7.40 (m, 7H, Ar–H), 3.87–3.82 (m, 2H, 2CHN), 1.38 (d, J=6.6 Hz, 12H, $4CH_3$). ^{13}C NMR ($CDCl_3$, 150 MHz): δ 190.7, 165.1, 145.6, 137.4, 135.3, 132.9, 130.5, 130.1, 129.1, 128.4, 127.9, 127.2, 125.2, 124.7, 51.3, 51.0, 20.5, 19.7. MS: m/z (%) 432 (M^+, 21), 416 (69), 387 (21), 232 (29), 117 (29), 105 (100). IR (KBr): ν=1664, 1535, 1451, 1322, 1199, 1124, 1069 cm^{-1}. Anal. Calcd for $C_{23}H_{23}F_3N_2OS$: C, 63.87; H, 5.36; N, 6.48; S, 7.41. Found: C, 63.64; H, 5.35; N, 6.49; S, 7.58.

*4.3.9. (4-Chlorophenyl)(5-phenyl-2-(pyrrolidin-1-yl)thiazol-4-yl) methanone (**10i**)* Operation as above with pyrrolidine (0.12 g, 1.3 mmol), compound **10i** (0.31 g, 84%) was also isolated as yellow solid. Mp: 146–148 °C. ^1H NMR ($CDCl_3$, 600 MHz): δ 7.92 (d, J=8.4 Hz, 2H, Ar–H), 7.32–7.20 (m, 7H, Ar–H), 3.52–3.46 (m, 4H, $2CH_2N$), 2.10–2.02 (m, 4H, $2CH_2$). ^{13}C NMR ($CDCl_3$, 150 MHz): δ 189.7, 164.8, 144.4, 139.0, 135.6, 131.7, 131.2, 130.6, 128.9, 128.3, 128.1, 127.6, 49.5, 25.6. MS: m/z (%) 368 (M^+, 100), 339 (27), 297 (12), 139 (61), 121 (30), 111 (54). IR (KBr): ν=1669, 1551, 1458, 1321, 1214, 1121, 1088 cm^{-1}. Anal. Calcd for $C_{23}H_{23}F_3N_2OS$: C, 65.12; H, 4.65; N, 7.59; S, 8.69. Found: C, 65.13; H, 4.47; N, 7.42; S, 8.88.

*4.3.10. 1-(5-Phenyl-2-(pyrrolidin-1-yl)thiazol-4-yl)ethanone (**10j**)* Operation as above with pyrrolidine (0.12 g, 1.3 mmol), compound **10j** (0.15 g, 55%) was also isolated as yellow oil. ^1H NMR ($CDCl_3$, 600 MHz): δ 7.48–7.32 (m, 5H, Ar–H), 3.49 (t, J=6.6 Hz, 4H, $2CH_2N$), 2.48 (s, 3H, CH_3), 2.07–2.05 (m, 4H, $2CH_2$). ^{13}C NMR ($CDCl_3$, 150 MHz): δ 195.1, 163.9, 144.7, 132.4, 131.5, 129.9, 129.7, 128.1, 128.0, 49.4, 30.1, 25.6. MS: m/z (%) 272 (M^+, 100), 244 (27), 217 (22), 121 (11), 70 (14). IR (KBr): ν=1687, 1557, 1483, 1352, 1278, 1146, 1071 cm^{-1}. Anal. Calcd for $C_{15}H_{16}N_2OS$: C, 66.15; H, 5.92; N, 10.29; S, 11.77. Found: C, 66.44; H, 5.77; N, 10.33; S, 11.97.

*4.3.11. 1-(2-(Diisopropylamino)-5-phenylthiazol-4-yl) ethanone (**10k**)* Operation as above with diisopropylamine (0.13 g, 1.3 mmol), compound **10k** (0.12 g, 40%) was also isolated as yellow oil. ^1H NMR ($CDCl_3$, 600 MHz): δ 7.51–7.34 (m, 5H, Ar–H), 3.82–3.78 (m, 2H, 2CHN), 2.55 (s, 3H, CH_3), 1.41 (d, J=6.6 Hz, 12H, $4CH_3$). ^{13}C NMR ($CDCl_3$, 150 MHz): δ 195.1, 163.9, 143.6, 133.0, 131.3, 131.0, 129.9, 129.8, 127.9, 51.4, 50.3, 30.3, 29.5, 20.6, 19.6. MS: m/z (%) 302 (M^+, 43), 259 (72), 245 (90), 218 (100), 185 (22), 140 (30). IR (KBr): ν=1687, 1541, 1451, 1367, 1286, 1137, 1096 cm^{-1}. Anal. Calcd for $C_{17}H_{22}N_2OS$: C, 67.51; H, 7.33; N, 9.26; S, 10.60. Found: C, 67.42; H, 7.47; N, 9.42; S, 10.79.

5. Crystallographic material

Compound **10b**: formula $C_{20}H_{18}N_2OS$, yellow crystal. The crystal is of monoclinic, space group $P2(1)/c$ with a=9.0184(8) Å, b=16.7580(14) Å, c=11.5065(10) Å, β=103.702(1)°, V=1689.5(3) $Å^3$, Z=4, D_{calcd}=1.315 g/cm^3, $F(000)$=704, μ=0.200 mm^{-1}, R=0.0568, and wR=0.1274 for 3311 observed reflections with $I>2\sigma(I_0)$. Crystallographic data for **10b** have been deposited in the Cambridge Crystallographic Data Center as supplementary publication numbers CCDC 867736. Copies of the data may be obtained, free of charge, on application to CCDC, 12 Union Road, Cambridge, CB2 1EZ, UK (fax: +44 1223 336033 or e-mail: deposit@ccdc.cam.ac.uk).

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Supplementary data

Supplementary data associated with this article can be found in the online version, at http://dx.doi.org/10.1016/j.tet.2012.07.002. These data include MOL files and InChiKeys of the most important compounds described in this article.

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