NJC

Cite this: *New J. Chem.*, 2011, **35**, 2607–2613

www.rsc.org/njc

PAPER

A green protocol for the synthesis of conformationally rigid sulfur linked bisquinolines by double Friedlander reaction in water†

Nidhin Paul,[a] Shanmugam Muthusubramanian*[a] and Nattamai Bhuvanesh[b]

Received (in Montpellier, France) 20th June 2011, Accepted 15th August 2011
DOI: 10.1039/c1nj20539k

A series of bis(2-aryl-4-arylquinolin-3-yl)sulfanes and 1,2-bis(2-aryl-4-arylquinolin-3-yl)disulfanes were synthesised in good to excellent yields by double Friedlander reaction between 2-[(2-oxo-2-arylethyl)sulfanyl]-1-aryl-1-ethanones/2-[(2-oxo-2-arylethyl)disulfanyl]-1-aryl-1-ethanones and 2-aminobenzophenone with *p*-toluenesulfonic acid in water medium. An interesting restricted rotation of aryl rings has been noticed in bis(2-aryl-4-arylquinolin-3-yl)sulfanes as revealed by NMR and crystal data.

Introduction

Although numerous biochemical organic reactions require the making or breaking of chemical bonds in an aqueous environment, water as a solvent was ruled out from organic reactions during the preceding decades. From the standpoint of green chemistry and its twelve principles,[1] water is the solvent of choice, being cheap, clean, inexpensive, non-toxic, non-polluting and non-flammable.[2] Due to hydrophobic effects,[3] water can not only accelerate reaction rates but also enhance the reaction selectivity.

Polyquinoline derivatives have found application in the field of electronics, optoelectronics and non-linear optics[4] and quinoline metal complexes are used in organic light emitting diodes.[5] Bisquinolines are well known heterocyclic compounds that contain two quinoline nuclei combined through an aliphatic or aromatic linker. Bisquinoline drugs such as Ro 47-7737, piperaquine and hydroxypiperaquine (Fig. 1) are active against chloroquine resistant strains of malaria and bisquinolines also have potential as antibiotics and antitumor agents.[6] In addition, these compounds are useful for studying the role of chromophores in natural compounds.[7]

Among the well-established methods for the preparation of quinolines,[8] the Friedlander approach is arguably the best known. Even though the two step Friedlander condensation, including enamine formation and cyclodehydration, has been performed under neutral, basic and acidic conditions,[9] subsequent work showed that acid catalysts are more effective.[10] Several catalysts such as Bronsted acids,[11] Lewis acids,[12] solid supported acids,[13] molecular iodine,[14] metals[15] and ionic liquids mediated catalysts[16] have been reported to be effective for this reaction.

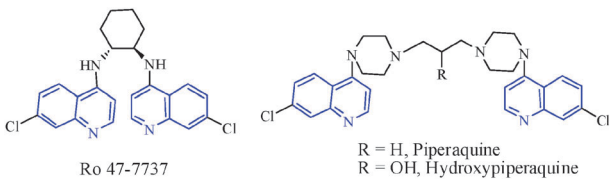


Fig. 1 Structures of bisquinoline antimalarial drugs.

In many of these procedures, the reaction is usually carried out in polar and in aprotic solvents such as acetonitrile, THF, DMSO and DMF. Though *p*-toluenesulfonic acid (*p*-TsOH) has been used in a variety of reactions to produce several heterocyclic compounds,[17] its use in Friedlander reaction is limited.[18] Synthesis of quinoline derivatives by the Friedlander method was reported in water, but requires stoichiometric amounts of mineral acid, metal dodecyl sulfates, dodecyl phosphonic acid, cyanuric chloride or Lewis acids.[19] In this article, we report a very efficient and environmentally benign strategy to get a set of conformationally rigid novel sulfur linked bisquinolines in excellent yields using *p*-toluenesulfonic acid in water.

Results and discussion

In the present investigation, the preparation of a series of bisquinoline derivatives [**3a–n**] has been achieved in excellent yields by the reaction of 2-aminobenzophenone **1** with substituted diphenacylsulfides[20] **2** in the presence of *p*-toluenesulfonic acid as catalyst in water medium (Scheme 1).

The effect of solvent and catalyst has been investigated on the formation of **3c** and the results are tabulated (Table 1). The reaction proceeds well in water with 10 mol% of *p*-toluenesulfonic acid compared to other trials. Base catalysts failed to effect the reaction even after prolonged heating. The reaction described in Scheme 1 has been carried out under optimized conditions (Table 2). It is to be noted that the formation of monoquinoline has not been noticed, whatever be the ratio of aminobenzophenone and diphenacyl sulfide, 1 : 1 or 2 : 1.

[a] *Department of Organic Chemistry, School of Chemistry, Madurai Kamaraj University, Madurai 625 021, India. E-mail: muthumanian2001@yahoo.com*
[b] *Department of Chemistry, Texas A & M University, College Station, TX 77843, USA*

† Electronic supplementary information (ESI) available. CCDC reference numbers 824667, 827881 and 827882. For ESI and crystallographic data in CIF or other electronic format see DOI: 10.1039/c1nj20539k

Scheme 1 Preparation of sulfur linked bisquinolines **3**.

Table 1 Catalyst and solvent screening for the formation of **3c**

Entry	Solvent	Catalyst	Mol%	Yield[a,b] (%)
1	H_2O	$AlCl_3$	20	26
2	H_2O	$ZnCl_2$	15	20
3	H_2O	HCl	15	64
4	H_2O	*p*-TsOH	10	96
5	CH_3OH	$AlCl_3$	30	55
6	CH_3OH	*p*-TsOH	25	78
7	CH_3CN	*p*-TsOH	25	73
8	THF	*p*-TsOH	25	61
9	—[c]	*p*-TsOH	20	38
10	CH_3OH	NaOH	15	—[d]

[a] Recrystallised from the dichloromethane–ethyl acetate mixture. [b] Isolated yield after purification by column chromatography. [c] No solvent. [d] No recognisable product can be isolated.

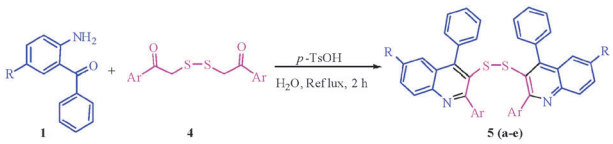
In order to broaden the scope of the proposed reaction, we also carried out the reaction of 2-aminobenzophenone **1** with diphenacyl disulfide[21] **4** under the above mentioned conditions (Scheme 2) to give **5a–e** and the results are encouraging (Table 2). The reusability of the reaction medium is also tested without much variation in conversion[22] and the yields were 92 and 89% for consecutive trials for **3a**.

The structures of bisquinolines **3** and **5** have been established unambiguously by NMR, mass and single crystal X-ray analyses. The molecular mass for the compounds **3b**, **3f**, **5a** and **5c** was obtained as *m*/*e* 621.2359 [M + 1] (calcd 621.2286 [M + 1]), 661.1266 [M + 1] (calcd 661.1194 [M + 1]), 725.0 [M + 1] (calcd 725.2 [M + 1]) and *m*/*e* 693.0 [M + 1] (calcd 693.1

Table 2 Yields of **3** and **5**

Compound	Ar	R	Time/h	Yield[a,b] (%)
3a	C_6H_5	H	1.1	93
3b	4-MeC_6H_4	H	1.2	95
3c	4-ClC_6H_4	H	2	96
3d	4-BrC_6H_4	H	1.5	94
3e	2-Naphthyl	H	1.2	91
3f	3-ClC_6H_4	H	1.5	93
3g	3-BrC_6H_4	H	1.5	95
3h	C_6H_5	Cl	1.5	92
3i	4-MeC_6H_4	Cl	1.2	94
3j	4-ClC_6H_4	Cl	2	95
3k	4-BrC_6H_4	Cl	1.1	92
3l	2-Naphthyl	Cl	1.4	90
3m	3-ClC_6H_4	Cl	1.5	95
3n	3-BrC_6H_4	Cl	2	96
5a	2-Naphthyl	H	2	93
5b	4-MeC_6H_4	H	1.6	94
5c	4-ClC_6H_4	H	1.5	91
5d	2-Naphthyl	Cl	2	96
5e	4-ClC_6H_4	Cl	1.5	93

[a] Isolated yield after recrystallisation from the dichloromethane–ethyl acetate (8 : 2) mixture. [b] All the compounds have melting points above 280 °C.



Scheme 2 Preparation of disulfide linked bisquinolines **5**.

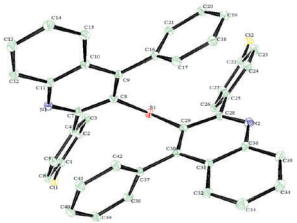


Fig. 2 ORTEP diagram of **3c**.

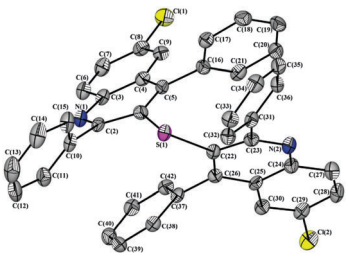


Fig. 3 ORTEP diagram of **3h**.

[M + 1]), respectively, in their mass spectra. The structure was also confirmed from single crystal X-ray analysis of **3c**, **3h** and **5e** (Fig. 2, 3 and 4).[23]

The NMR spectral data for **3** and **5** are very significant, revealing interesting conformational features. The symmetrical sulfide **3i** is expected to exhibit seventeen carbon signals in the aryl region of the ^{13}C NMR spectrum, out of which eight are to be methine carbons, rest being quaternary. But the ^{13}C NMR spectrum of **3i** exhibits nineteen carbon signals in the aryl region, ten of them being methine carbons. The quinoline H-8 proton appears as doublet at 7.90 ppm (J = 9.0 Hz), H-7 as doublet of doublet at 7.53 ppm (J = 9.0, 2.1 Hz) and H-5 as a doublet at 7.12 (J = 2.1 Hz). Two other doublets at 6.64 ppm (J = 7.5 Hz) and 6.95 ppm (J = 7.5 Hz) have common HMBC contours with a quaternary carbon, indicating them to be the non-equivalent *ortho* hydrogens of the aryl ring either at C-2 or at C-4. It is very clear from the number of methine carbons in DEPT-135 and the non-equivalence of the *ortho* hydrogens of one aryl ring that one of the aryl rings has

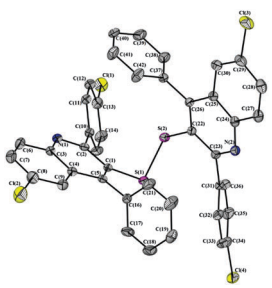


Fig. 4 ORTEP diagram of **5e**.

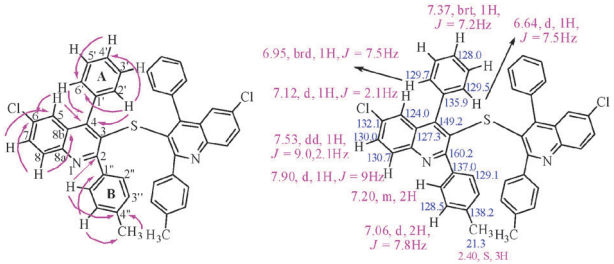


Fig. 5 NMR chemical shifts and HMBCs of **3i**.

all its six carbons non-equivalent. For a phenyl ring or a *para* substituted phenyl ring this is unexpected, unless the rotation of the C–C bond is slow enough to feel different chemical environment. A conformationally biased[24] arrangement has to be ascribed for this observation. It is confirmed that C-4 aryl and not C-2 aryl has this restricted rotation by introducing a *meta* substituted aryl ring in the C-2 position (**3f**, **3g**, **3m** and **3n**), when the number of carbon signals in the aryl region of the ^{13}C NMR spectrum is increased by two. The complete assignment of hydrogen and carbon signals for **3i** has been achieved by analysing the two dimensional NMR spectral data (Fig. 5).

The upfield chemical shift values of the *ortho* hydrogens of the aryl ring under discussion suggest that these two hydrogens are under the influence of the ring current effect of the quinoline ring, experiencing the shielding due to the near perpendicular orientation of this ring with respect to the quinoline nucleus. It must be mentioned that the crystal structure also supports this proposed preferred conformation in solution. An energy minimised structure for **3a** predicted by semi-empirical AMI calculation using ArgusLab software[25] also has a similar arrangement (Fig. 6).

The NMR spectral features of the bisquinoline linked by the disulfide are still more interesting. In the ^{1}H NMR spectrum of **5b**, the quinoline ring hydrogens appear well resolved (Fig. 7). Thus the C-8 hydrogen appears as a doublet at 8.19 ppm (J = 8.1 Hz), C-7 hydrogen as a triplet at 7.77 ppm (J = 8.1 Hz), C-6 hydrogen as another triplet at 7.41 ppm (J = 8.1 Hz) and the C-5 hydrogen at 7.20 ppm as a doublet (J = 8.1 Hz). But the C-2 and C-4 aryl ring hydrogens are not well resolved appearing as broad peaks around 7.3 (8H) and 6.9 ppm (10H). In the H,H-COSY spectrum of **5b**, there is no contour connecting 7.3 and 6.9 ppm peaks, indicating that the former is exclusively for one aryl ring and the latter is for another ring. In the ^{13}C NMR spectrum, it is observed that (i) not all the carbons are being picked up and (ii) a few carbons are appearing unusually broad and less intense. The C-2 and

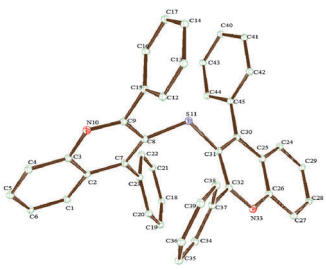


Fig. 6 Energy minimized structure for **3a**.

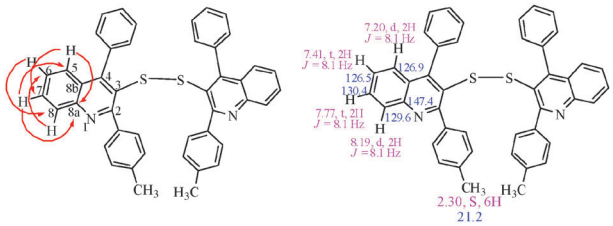


Fig. 7 NMR chemical shifts and HMBCs of **5b**.

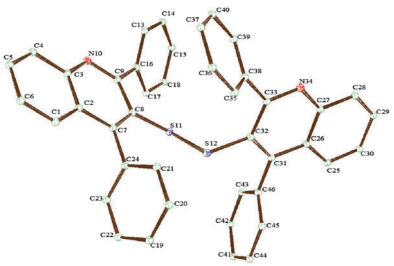


Fig. 8 Energy minimized structure for di(2,4-diphenyl-3-quinolyl) disulfide.

C-4 aryl ring hydrogens are not giving any HMBC contours with any of the quaternary carbons preventing assignment of the observed carbon signals. There is no appreciable change in the NMR spectral pattern of these compounds, even when the solvent was changed to DMSO-d_6 or acetone-d_6 from $CDCl_3$. Probably a dynamic conformational switching might have led to the above observations in the NMR spectra.

An energy minimized structure for di(2,4-diphenyl-3-quinolyl) disulfide (Fig. 8) is given for comparison.

Conclusion

Mono- and di-sulfur linked bisquinolines have been synthesized using *p*-toluenesulfonic acid in water through a green Friedlander approach. The restricted rotation in the compounds has been investigated using NMR, crystal and mass analysis. The mono-sulfur linked bisquinolines exhibit conformational rigidity with all the hydrogen and carbons of the C-4 aryl being non-equivalent in their NMR spectra. The disulfur linked compounds also have unusual NMR patterns.

Experimental section

All melting points reported in this work were measured in open capillaries. The ^{1}H, ^{13}C NMR and 2D NMR spectra have been measured at 300 and 75 MHz, respectively, using a Bruker 300 MHz (Avance) instrument in $CDCl_3$ and using tetramethylsilane (TMS) as internal standard. Chemical shifts are reported as δ values (ppm). For compounds **5a–e**, all the carbon signals are not picked up. All one- and two-dimensional NMR spectra were obtained using standard Bruker software throughout. Silica gel-G plates (Merck) were used for TLC analysis with a mixture of petroleum ether (60–80 °C) and ethyl acetate as eluent. Elemental analyses were performed on a Perkin Elmer 2400 Series II Elemental CHNS analyzer. IR spectra were recorded on a JASCO FT IR instrument (KBr pellet method). Crystals suitable for X-ray crystallographic

studies were obtained by crystallization from a 1 : 1 mixture of dichloromethane and DMF.

General procedure for quinoline derivatives (3/5)

2-[(2-Oxo-2-arylethyl)sulfanyl]-1-aryl-1-ethanone/2-[(2-oxo-2-phenylethyl)disulfanyl]-1-aryl-1-ethanone **2**/**4** (0.1 mole) and 2-amino benzophenone **1** (0.2 mole) were taken in 15 mL water followed by the addition of *p*-toluenesulfonic acid (10 mol%) and refluxed for 1–2 h. After the completion of the reaction (monitored by TLC), the mixture was cooled to room temperature and the solid was filtered out and recrystallised from the dichloromethane–ethyl acetate (8 : 2) mixture to yield a pure product. Spectral data of all the compounds are given below.

Di(2,4-diphenyl-3-quinolyl) sulfide (3a). Isolated as a colorless solid; IR (KBr): 3057 (C-H), 1560 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 6.67 (d, 2H, J = 7.5 Hz, Ar-H), 6.95 (d, 2H, J = 7.5 Hz, Ar-H), 7.12–7.18 (m, 4H, Ar-H), 7.24–7.35 (m, 16H, Ar-H), 7.59 (td, 2H, J = 8.4, 1.5 Hz, Ar-H), 7.98 (d, 2H, J = 8.4 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 125.3, 126.4, 126.7, 127.6, 127.7, 127.8, 127.9, 128.0, 128.5, 129.0, 129.1, 129.2, 129.7, 129.9, 136.4, 140.2, 145.9, 150.3, 160.0. Anal. calcd for $C_{42}H_{28}N_2S$: C, 85.10; H, 4.76; N, 4.73%. Found C, 85.06; H, 4.73; N, 4.78%.

Di[2-(4-methylphenyl)-4-phenyl-3-quinolyl] sulfide (3b). Isolated as a colorless solid; IR (KBr): 3059 (C-H), 1560 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 2.39 (s, 6H, CH_3), 6.62 (d, 2H, J = 7.5 Hz, Ar-H), 6.96 (d, 2H, J = 7.5 Hz, Ar-H), 7.05 (d, 4H, J = 8.1 Hz, Ar-H), 7.13–7.21 (m, 8H, Ar-H), 7.25–7.35 (m, 6H, Ar-H), 7.59 (td, 2H, J = 8.4, 1.5 Hz, Ar-H), 7.96 (d, 2H, J = 8.4 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 21.4, 125.3, 126.2, 126.8, 127.6, 127.9, 128.1, 128.5, 128.7, 129.0, 129.1, 129.2, 129.6, 129.8, 136.6, 137.4, 137.9, 146.0, 150.1, 160.1; m/e 621.2359 [M + 1] (calcd 621.2286 [M + 1]); Anal. calcd for $C_{44}H_{32}N_2S$: C, 85.13; H, 5.20; N, 4.51%. Found C, 85.10; H, 5.17; N, 4.55%.

Di[2-(4-chlorophenyl)-4-phenyl-3-quinolyl] sulfide (3c). Isolated as a colorless solid; IR (KBr): 3055 (C-H), 1558 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 6.65 (d, 2H, J = 7.2 Hz, Ar-H), 6.92 (d, 2H, J = 7.5 Hz, Ar-H), 7.14–7.28 (m, 12H, Ar-H), 7.33–7.39 (m, 6H, Ar-H), 7.67 (t, 2H, J = 8.4 Hz, Ar-H), 8.15 (d, 2H, J = 8.4 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 125.4, 126.8, 127.2, 128.0, 128.1 (2C), 128.2, 128.3, 128.4, 129.5, 129.7, 130.1, 130.7, 134.8, 135.9, 137.1, 145.0, 151.6, 158.3. Anal. calcd for $C_{42}H_{26}Cl_2N_2S$: C, 76.24; H, 3.96; N, 4.23%. Found C, 76.19; H, 3.93; N, 4.27%.

Di[2-(4-bromophenyl)-4-phenyl-3-quinolyl] sulfide (3d). Isolated as a colorless solid; IR (KBr): 3057 (C-H), 1557 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 6.66 (d, 2H, J = 7.2 Hz, Ar-H), 6.90 (d, 2H, J = 7.5 Hz, Ar-H), 7.11–7.23 (m, 10H, Ar-H), 7.29–7.37 (m, 8H, Ar-H), 7.63 (td, 2H, J = 8.4, 1.2 Hz, Ar-H), 7.99 (d, 2H, J = 8.4 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 122.7, 125.3, 126.8 (2C), 127.9, 128.0 (2C), 128.2, 129.2, 129.5, 129.7, 129.9, 130.8, 130.9, 136.2, 139.0, 146.0, 150.7, 158.8. Anal. calcd for $C_{42}H_{26}Br_2N_2S$: C, 67.21; H, 3.49; N, 3.73%. Found C, 67.17; H, 3.46; N, 3.77%.

Di[2-(2-naphthyl)-4-phenyl-3-quinolyl] sulfide (3e). Isolated as a colorless solid; IR (KBr): 3054 (C-H), 1560 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 6.75 (d, 2H, J = 7.8 Hz, Ar-H), 6.79 (d, 2H, J = 8.1 Hz, Ar-H), 7.08–7.17 (m, 4H, Ar-H), 7.20 (d, 2H, J = 1.5 Hz, Ar-H), 7.26–7.32 (m, 4H, Ar-H), 7.38 (t, 2H, J = 7.2 Hz, Ar-H), 7.45–7.63 (m, 12H, Ar-H), 7.89 (t, 4H, J = 9.0 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 125.3, 125.8, 126.4 (2C), 127.0, 126.8, 127.4, 127.5, 127.8, 127.9, 128.0, 128.5, 128.7, 129.0, 129.2 (2C), 129.8, 130.2, 132.8, 133.0, 136.4, 137.8, 146.0, 150.6, 160.2. Anal. calcd for $C_{50}H_{32}N_2S$: C, 86.67; H, 4.66; N, 4.04%. Found C, 86.63; H, 4.63; N, 4.09%.

Di[2-(3-chlorophenyl)-4-phenyl-3-quinolyl] sulfide (3f). Isolated as a colorless solid; IR (KBr): 3056 (C-H), 1560 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 6.68 (d, 2H, J = 7.2 Hz, Ar-H), 6.92 (d, 2H, J = 7.5 Hz, Ar-H), 7.09–7.17 (m, 4H, Ar-H), 7.19–7.40 (m, 14H, Ar-H), 7.64 (td, 2H, J = 8.4, 1.5 Hz, Ar-H), 8.00 (d, 2H, J = 8.4 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 125.3, 126.8, 126.9, 127.3, 128.0, 128.1, 128.2 (2C), 128.3, 129.0, 129.2, 129.3, 129.5, 129.8, 129.9, 133.8, 136.1, 141.9, 145.9, 150.9, 158.7; m/e 661.1266 [M + 1] (calcd 661.1194 [M + 1]); Anal. calcd for $C_{42}H_{26}Cl_2N_2S$: C, 76.24; H, 3.96; N, 4.23%. Found C, 76.20; H, 3.93; N, 4.27%.

Di[2-(3-bromophenyl)-4-phenyl-3-quinolyl] sulfide (3g). Isolated as a colorless solid; IR (KBr): 3054 (C-H), 1559 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 6.66 (d, 2H, J = 7.8 Hz, Ar-H), 6.93 (d, 2H, J = 7.2 Hz, Ar-H), 7.09 (t, 2H, J = 7.8 Hz, Ar-H), 7.16–7.23 (m, 6H, Ar-H), 7.25 (d, 2H, J = 1.2 Hz, Ar-H), 7.30–7.40 (m, 6H, Ar-H), 744 (dd, 2H, J = 7.8, 1.2 Hz, Ar-H), 7.64 (t, 2H, J = 8.4 Hz, Ar-H), 8.01 (d, 2H, J = 8.4 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 122.1, 125.3, 126.8, 126.9, 127.8, 128.0 (3C), 128.3, 129.2, 129.4, 129.6, 129.7, 129.9, 131.1, 132.1, 136.1, 142.1, 145.9, 150.9, 158.6. Anal. calcd for $C_{42}H_{26}Br_2N_2S$: C, 67.21; H, 3.49; N, 3.73% Found C, 67.18; H, 3.44; N, 3.78%.

Di(6-chloro-2,4-diphenyl-3-quinolyl) sulfide (3h). Isolated as a colorless solid; IR (KBr): 3056 (C-H), 1561 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 6.67 (d, 2H, J = 7.5 Hz, Ar-H), 6.95 (d, 2H, J = 7.5 Hz, Ar-H), 7.14 (d, 2H, J = 2.1 Hz, Ar-H), 7.17–7.39 (m, 16H, Ar-H), 7.53 (dd, 2H, J = 9.0, 2.1 Hz, Ar-H), 7.91 (d, 2H, J = 9.0 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 124.0, 127.3, 127.8, 128.1, 128.2 (2C), 128.3, 129.1, 129.4, 129.6, 129.8, 130.1, 130.7, 132.4, 135.7, 139.8, 144.3, 149.4, 160.1. Anal. calcd for $C_{42}H_{26}Cl_2N_2S$: C, 76.24; H, 3.96; N, 4.23%. Found C, 76.20; H, 3.93; N, 4.27%.

Di[6-chloro-2-(4-methylphenyl)-4-phenyl-3-quinolyl] sulfide (3i). Isolated as a colorless solid; IR (KBr): 3052 (C-H), 1555 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 2.40 (s, 6H, CH_3), 6.64 (d, 2H, J = 7.5 Hz, Ar-H), 6.95 (d, 2H, J = 7.5 Hz, Ar-H), 7.07 (d, 4H, J = 7.8 Hz, Ar-H), 7.12 (d, 2H, J = 2.1 Hz, Ar-H), 7.16–7.24 (m, 8H, Ar-H), 7.37 (t, 2H, J = 7.2 Hz, Ar-H), 7.53 (dd, 2H, J = 9.0, 2.1 Hz, Ar-H), 7.90 (d, 2H, J = 9.0 Hz, Ar-H); ^{13}C NMR (75 MHz,

$CDCl_3$) δ_C: 21.3, 124.0, 127.3, 128.0, 128.2, 128.3, 128.5, 129.1, 129.5, 129.6, 129.7, 130.0, 130.7, 132.1, 135.9, 137.0, 138.2, 144.4, 149.2, 160.2. Anal. calcd for $C_{44}H_{30}Cl_2N_2S$: C, 76.62; H, 4.38; N, 4.06%. Found C, 76.59; H, 4.34; N, 4.10%.

Di[6-chloro-2-(4-chlorophenyl)-4-phenyl-3-quinolyl] sulfide (3j). Isolated as a colorless solid; IR (KBr): 3059 (C-H), 1557 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 6.64 (d, 2H, J = 7.2 Hz, Ar-H), 6.89 (d, 2H, J = 7.5 Hz, Ar-H), 7.13 (d, 2H, J = 2.4 Hz, Ar-H), 7.17–7.28 (m, 12H, Ar-H), 7.38 (t, 2H, J = 7.5 Hz, Ar-H), 7.57 (dd, 2H, J = 9.0, 2.4 Hz, Ar-H), 7.92 (d, 2H, J = 9.0 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 124.1, 127.4, 128.1, 128.3, 128.4 (2C), 129.1, 129.4, 129.7, 130.5, 130.6, 130.8, 132.8, 134.6, 135.6, 138.0, 144.4, 149.8, 158.9. Anal. calcd for $C_{42}H_{24}Cl_4N_2S$: C, 69.05; H, 3.31; N, 3.83%. Found C, 69.00; H, 3.28; N, 3.87% .

Di[2-(4-bromophenyl)-6-chloro-4-phenyl-3-quinolyl] sulfide (3k). Isolated as a colorless solid; IR (KBr): 3058 (C-H), 1558 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 6.65 (d, 2H, J = 7.8 Hz, Ar-H), 6.89 (d, 2H, J = 7.5 Hz, Ar-H), 7.14 (d, 2H, J = 2.4 Hz, Ar-H), 7.16–7.28 (m, 6H, Ar-H), 7.33–7.44 (m, 8H, Ar-H), 7.57 (dd, 2H, J = 9.0, 2.4 Hz, Ar-H), 7.92 (d, 2H, J = 9.0 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 118.4, 123.0, 124.1, 127.4, 128.2, 128.3, 129.0, 129.1, 129.5, 129.7, 130.5, 130.8, 131.0, 132.8, 135.5, 138.5, 144.4, 149.8, 158.9. Anal. calcd for $C_{42}H_{24}Br_2Cl_2N_2S$: C, 61.56; H, 2.95; N, 3.42%. Found C, 61.52; H, 2.90; N, 3.46%

Di[6-chloro-2-(2-naphthyl)-4-phenyl-3-quinolyl] sulfide (3l). Isolated as a colorless solid; IR (KBr): 3054 (C-H), 1554 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 6.74 (d, 2H, J = 7.5 Hz, Ar-H), 6.80 (d, 2H, J = 7.8 Hz, Ar-H), 7.12–7.22 (m, 6H, Ar-H), 7.30 (t, 2H, J = 7.5 Hz, Ar-H), 7.39 (t, 2H, J = 7.2 Hz, Ar-H), 7.47–7.65 (m, 12H, Ar-H), 7.82 (d, 2H, J = 9.0 Hz, Ar-H), 7.87 (d, 2H, J = 7.8 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 123.9, 126.0, 126.4, 126.6, 127.0, 127.3, 127.5 (2C), 128.1, 128.2, 128.5, 128.6, 129.7, 129.8, 130.0, 130.1, 130.8, 132.4, 132.6, 133.0, 135.6, 137.2, 144.3, 149.7, 160.2. Anal. calcd for $C_{50}H_{30}Cl_2N_2S$: C, 78.84; H, 3.97; N, 3.68%. Found C, 78.80; H, 3.94; N, 3.72%.

Di[6-chloro-2-(3-chlorophenyl)-4-phenyl-3-quinolyl] sulfide (3m). Isolated as a colorless solid; IR (KBr): 3059 (C-H), 1561 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 6.69 (d, 2H, J = 7.5 Hz, Ar-H), 6.91 (d, 2H, J = 7.5 Hz, Ar-H), 7.10–7.19 (m, 6H, Ar-H), 7.24–7.33 (m, 8H, Ar-H), 7.41 (td, 2H, J = 7.5, 1.8 Ar-H), 7.57 (dd, 2H, J = 9.0, 2.1 Hz, Ar-H), 7.94 (d, 2H, J = 9.0 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 124.1, 127.3, 127.4, 128.4, 128.5 (3C), 129.1, 129.2 (2C), 129.6, 129.8, 130.5, 130.9, 133.0, 133.9, 135.4, 141.4, 144.3, 150.0, 158.8. Anal. calcd for $C_{42}H_{24}Cl_4N_2S$: C, 69.05; H, 3.31; N, 3.83%. Found C, 69.00; H, 3.28; N, 3.88%.

Di[2-(3-bromophenyl)-6-chloro-4-phenyl-3-quinolyl] sulfide (3n). Isolated as a colorless solid; IR (KBr): 3057 (C-H), 1562 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 6.67 (d, 2H, J = 7.8 Hz, Ar-H), 6.92 (d, 2H, J = 7.5 Hz, Ar-H), 7.09–7.23 (m, 4H, Ar-H), 7.26–7.29 (m, 4H, Ar-H), 7.38–7.48 (m, 8H, Ar-H), 7.58 (dd, 2H, J = 9.0, 2.4 Hz, Ar-H), 7.95 (d, 2H, J = 9.0 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 122.2, 124.1, 127.5, 127.7, 128.3, 128.4, 128.5, 129.2, 129.3, 129.6, 129.8, 130.6, 131.0, 131.4, 132.1, 133.0, 135.4, 141.6, 144.3, 150.0, 158.7. Anal. calcd for $C_{42}H_{24}Br_2Cl_2N_2S$: C, 61.56; H, 2.95; N, 3.42%. Found C, 61.52; H, 2.90; N, 3.47%.

Di[2-(2-naphthyl)-4-phenyl-3-quinolyl] disulfide (5a). Isolated as a colorless solid; IR (KBr): 3058 (C-H), 1561 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 7.04 (b, 2H Ar-H), 7.20 (b, 8H, Ar-H), 7.41–7.47 (m, 16H, Ar-H), 7.78–7.83 (m, 4H, Ar-H), 8.20 (d, 2H, J = 8.4 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 125.8, 126.3, 126.7, 126.8, 127.0, 127.2, 127.4, 127.7 (3C), 128.5, 129.2, 129.6, 130.5, 132.7, 132.8, 136.5, 137.8, 147.2, 154.2, 162.7; m/e 725.0 [M + 1] (calcd 725.2 [M + 1]); Anal. calcd for $C_{50}H_{32}N_2S_2$: C, 82.84; H, 4.45; N, 3.86%. Found C, 82.80; H, 4.42; N, 3.89%.

Di[2-(4-methylphenyl)-4-phenyl-3-quinolyl] disulfide (5b). Isolated as a colorless solid; IR (KBr): 3057 (C-H), 1559 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 2.30 (s, 6H, CH_3), 6.87 (b, 10H, Ar-H), 7.20 (d, 2H, J = 8.1 Hz, Ar-H), 7.30 (b, 8H, Ar-H), 7.41 (t, 2H, J = 8.1 Hz, Ar-H), 7.77 (t, 2H, J = 8.1 Hz, Ar-H), 8.19 (d, 2H, J = 8.1 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 21.2, 126.5, 126.9, 127.6, 128.0, 129.6 (2C), 130.4, 136.8, 137.4, 137.8, 147.4, 154.3, 162.9. Anal. calcd for $C_{44}H_{32}N_2S_2$: C, 80.95; H, 4.94; N, 4.29%. Found C, 80.90; H, 4.90; N, 4.33%.

Di[2-(4-chlorophenyl)-4-phenyl-3-quinolyl] disulfide (5c). Isolated as a colorless solid; IR (KBr): 3059 (C-H), 1561 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 6.97 (b, 6H, Ar-H), 7.11 (b, 8H, Ar-H), 7.23 (d, 2H, J = 8.1 Hz, Ar-H), 7.36 (b, 4H, Ar-H), 7.45 (t, 2H, J = 8.1 Hz, Ar-H), 7.79 (td, 2H, J = 8.1, 0.9 Hz, Ar-H), 8.19 (d, 2H, J = 8.1 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 127.1, 127.2, 127.6, 127.8, 127.9, 129.6(2C), 130.8, 131.2, 134.1, 136.5, 138.7, 147.3, 154.1, 161.4; m/e 693.0 [M + 1] (calcd 693.1 [M + 1]); Anal. calcd for $C_{42}H_{26}Cl_2N_2S_2$: C, 72.72; H, 3.78; N, 4.04%. Found C, 72.69; H, 3.74; N, 4.09%.

Di[6-chloro-2-(2-naphthyl)-4-phenyl-3-quinolyl] disulfide (5d). Isolated as a colorless solid; IR (KBr): 3055 (C-H), 1561 (C=N) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ_H: 7.10 (b, 10H Ar-H), 7.48 (b, 14H, Ar-H), 7.74 (dd, 2H, J = 9.0, 2.1 Hz, Ar-H), 7.78 (b, 2H, Ar-H), 8.13 (d, 2H, J = 9.0 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 125.6, 126.0, 126.5, 126.8, 127.2, 127.5, 127.9, 128.2, 128.4, 128.6, 129.3, 129.6, 131.3, 131.5, 132.6, 132.8, 132.9, 135.8, 137.4, 145.8, 154.0, 162.8. Anal. calcd for $C_{50}H_{30}Cl_2N_2S_2$: C, 75.65; H, 3.81; N, 3.53%. Found C, 75.62; H, 3.78; N, 3.58%.

Di[6-chloro-2-(4-chlorophenyl)-4-phenyl-3-quinolyl] disulfide (5e). Isolated as a colorless solid; IR (KBr): 3057 (C-H), 1559 (C=N) cm^{-1}; yield: ^1H NMR (300 MHz, $CDCl_3$) δ_H: 6.99 (br s, 8H, Ar-H), 7.14 (b, 6H Ar-H), 7.18 (d, 2H, J = 2.4 Hz, Ar-H), 7.42 (b, 4H, Ar-H), 7.74 (dd, 2H, J = 8.7, 2.4 Hz, Ar-H), 8.12 (d, 2H, J = 8.7 Hz, Ar-H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 125.7, 127.6, 128.0 (2C), 128.3, 129.3, 131.0, 131.1, 131.8, 133.2, 134.4, 135.7, 138.1, 145.6, 154.2, 161.4. Anal. calcd for $C_{42}H_{24}Cl_4N_2S_2$: C, 66.15; H, 3.17; N, 3.67%. Found C, 66.11; H, 3.14; N, 3.70%.

Acknowledgements

The authors thank DST for funds under IRHPA program towards high resolution NMR spectrometer. Financial support from UGC, New Delhi, to NP is gratefully acknowledged.

Notes and references

1 (*a*) P. T. Anastas and J. C. Warner, *Green Chemistry: Theory and Practice*, Oxford University Press, New York, 1998, p.30; (*b*) D. L. Hjeresen, M. M. Kirchhoff and R. L. Lankey, *Corp. Environ. Strategy*, 2002, **9**, 259; (*c*) J. C. Warner, A. S. Cannon and K. M. Dye, *Environ. Impact Assess. Rev.*, 2004, **24**, 775.

2 (*a*) D. Q. Xu, J. Wu, S. P. Luo, J. X. Zhang, J. Y. Wu, X. H. Du and Z. Y. Xu, *Green Chem.*, 2009, **11**, 1239; (*b*) D. Amantini, F. Fringuelli, O. Piermatti, F. Pizzo and L. Vaccaro, *Green Chem.*, 2001, **3**, 229; (*c*) H. Li, W. Chai, F. Zhang and J. Chen, *Green Chem.*, 2007, **9**, 1223; (*d*) M. Raja and V. K. Singh, *Chem. Commun.*, 2009, 6687.

3 (*a*) X.-P. Fu, L. Liu, D. Wang, Y.-J. Chen and C.-J. Li, *Green Chem.*, 2011, **13**, 549; (*b*) S. Chitra, N. Paul, S. Muthusubramanian and P. Manisankar, *Green Chem.*, 2011, DOI: 10.1039/C1GC15483D; (*c*) A. Fihri, D. Luart, C. Len, A. Solhy, C. Chevrin and V. Polshettiwar, *Dalton Trans.*, 2011, **40**, 3116; (*d*) M. Ueno, T. Kitanosono, M. Sakai and S. Kobayashi, *Org. Biomol. Chem.*, 2011, **9**, 3619; (*e*) A. Dandia, R. Singh, S. Bhaskaran and S. D. Samant, *Green Chem.*, 2011, **13**, 1852; (*f*) W. Blokzijl and J. B. F. N. Engberts, *Angew. Chem., Int. Ed. Engl.*, 1993, **32**, 1545; (*g*) X. Zhang, X. Jia, J. Wang and X. Fan, *Green Chem.*, 2011, **13**, 413; (*h*) J. B. F. N. Engberts, *Pure Appl. Chem.*, 1995, **67**, 823; (*i*) S. Otto and J. B. F. N. Engberts, *Org. Biomol. Chem.*, 2003, **1**, 2809.

4 (*a*) A. K. Agarwal and S. A. Jenekhe, *Macromolecules*, 1991, **24**, 6806; (*b*) X. Zhang, A. S. Shetty and S. A. Jenekhe, *Macromolecules*, 1999, **32**, 7422.

5 R. P. Korivi and C. H. Cheng, *J. Org. Chem.*, 2006, **71**, 7079 and the references cited therein.

6 (*a*) M. Nasr and J. H. Burckhalter, *J. Heterocycl. Chem.*, 1979, **16**, 497; (*b*) J. L. Vannerstrom, W. Y. Ellis, A. L. Ager, S. L. Andersen, L. Gerena and W. K. Milhous, *J. Med. Chem.*, 1992, **35**, 2129; (*c*) K. Raynes, D. Galatis, A. F. Cowman, L. Tilley and L. W. Deady, *J. Med. Chem.*, 1995, **38**, 204.

7 T. V. Alfredson, A. H. Maki and A. J. Warning, *Biochemistry*, 1991, **30**, 9665.

8 (*a*) Z. H. Skraup, *Monatsh. Chem.*, 1880, **1**, 316; (*b*) W. Pfitzinger, *J. Prakt. Chem.*, 1886, **33**, 100; (*c*) P. Friedlander, *Ber. Dtsch. Chem. Ges.*, 1882, **15**, 2572; (*d*) J. Li, D. W. Kung and D. A. Griffith, *Tetrahedron Lett.*, 2010, **51**, 3876; (*e*) R. G. Gould and W. A. Jacobs, *J. Am. Chem. Soc.*, 1939, **61**, 2890; (*f*) O. Meth-Cohn, *Heterocycles*, 1993, **35**, 539; (*g*) A. K. Verma, S. P. Shukla, J. Singh and V. Rustagi, *J. Org. Chem.*, 2011, **76**, 5670; (*h*) S. Ali, H.-T. Zhu, X.-F. Xia, K.-G. Ji, Y.-F. Yang, X.-R. Song and Y.-M. Liang, *Org. Lett.*, 2011, **13**, 2598; (*i*) S. Nagarajan, P. Arjun, N. Raaman and T. Mohan Das, *Carbohydr. Res.*, 2010, **345**, 1988; (*j*) C. Ronco, L. Jean and P.-Y. Renard, *Tetrahedron*, 2010, **66**, 7399; (*k*) D. dos Santos Pisoni, J. S. da Costa, D. Gamba, C. L. Petzhold, A. C. de A. Borges, M. A. Ceschi, P. Lunardi and C. A. S. Gonçalves, *Eur. J. Med. Chem.*, 2010, **45**, 526; (*l*) L. Zhu, Z. Miao, C. Sheng, W. Guo, J. Yao, W. Liu, X. Che, W. Wang, P. Cheng and W. Zhang, *Eur. J. Med. Chem.*, 2010, **45**, 2726; (*m*) R. Bujok, A. Kwast, P. Cmoch and Z. Wrobel, *Tetrahedron*, 2010, **66**, 698; (*n*) J. Defaux, M. Sala, X. Formosa, C. Galdeano, M. C. Taylor, W. A. A. Alobaid, J. M. Kelly, C. W. Wright, P. Camps and D. Muñoz-Torrero, *Bioorg. Med. Chem.*, 2011, **19**, 1702; (*o*) A. Khorshidi and K. Tabatabaeian, *J. Mol. Catal. A: Chem.*, 2011, **344**, 128; (*p*) K. K. Kumar and T. Mohan Das, *Carbohydr. Res.*, 2011, **346**, 728; (*q*) B. V. Subba Reddy and H. Grewal, *Tetrahedron Lett.*, 2011, **52**, 761; (*r*) A. Teimouri and A. N. Chermahini, *Arabian J. Chem.*, 2011, DOI: 10.1016/j.arabjc. 2011.05.018; (*s*) A. Kulkarni and B. Torok, *Green Chem.*, 2010, **12**, 875; (*t*) R. N. Monrad and R. Madsen, *Org. Biomol. Chem.*, 2011, **9**, 610; (*u*) W. Luo, Q. Mu, W. Qiu, T. Liu, F. Yang, X. Liu and J. Tang, *Tetrahedron*, 2011, **67**, 7090; (*v*) X. Li, Z. Mao, Y. Wang, W. Chen and X. Lin, *Tetrahedron*, 2011, **67**, 3858; (*w*) J. Marco-Contelles, E. Perez-Mayoral, A. Samadi, M. do Carmo Carreiras and E. Soriano, *Chem. Rev.*, 2009, **109**, 2652.

9 (*a*) D. Yang, K. Jiang, J. Li and F. Xu, *Tetrahedron*, 2007, **63**, 7654; (*b*) W. Borsche and F. Sinn, *Justus Liebigs Ann. Chem.*, 1939, **538**, 283; (*c*) E. A. Fehnel and D. E. Cohn, *J. Org. Chem.*, 1966, **31**, 3852.

10 (*a*) E. A. Fehnel, *J. Heterocycl. Chem.*, 1967, **4**, 565; (*b*) E. A. Fehnel, *J. Org. Chem.*, 1966, **31**, 2899; (*c*) M. del M. Blanco, C. Avendano and J. C. Menendez, *Tetrahedron*, 1999, **55**, 12637; (*d*) L. Strekowski, A. Czarny and H. Lee, *J. Fluorine Chem.*, 2000, **104**, 281; (*e*) Y.-Z. Hu, G. Zhang and R. P. Thummel, *Org. Lett.*, 2003, **5**, 2251.

11 (*a*) G. C. Muscia, M. Bollini, J. P. Carnevale, A. M. Bruno and S. E. Asıs, *Tetrahedron Lett.*, 2006, **47**, 8811; (*b*) M. Dabiri, M. Baghbanzadeh and M. S. Nikcheh, *Monatsh. Chem.*, 2007, **138**, 1249; (*c*) J. S. Yadav, P. Purushothama Rao, D. Sreenu, R. Srinivasa Rao, V. Naveen Kumar, K. Nagaiah and A. R. Prasad, *Tetrahedron Lett.*, 2005, **46**, 7249; (*d*) M. Barbero, S. Bazzi, S. Cadamuro and S. Dughera, *Tetrahedron Lett.*, 2010, **51**, 2342.

12 (*a*) S. Genovese, F. Epifano, M. C. Marcotullio, C. Pelucchini and M. Curini, *Tetrahedron Lett.*, 2011, **52**, 3474; (*b*) S. Chitra, N. Paul, S. Muthusubramanian, P. Manisankar, P. Yogeeswari and D. Sriram, *Eur. J. Med. Chem.*, 2011, DOI: 10.1016/j.ejmech.2011.07.046; (*c*) J. S. Yadav, B. V. S. Reddy, P. Sreedhar, R. S. Rao and K. Nagaiah, *Synthesis*, 2004, 2381; (*d*) E. Soleimani, M. M. Khodaei, N. Batooie and S. Samadi, *Chem. Pharm. Bull.*, 2010, **58**, 212 and the ref cited there in; (*e*) B. R. Mc Naughton and B. L. Miller, *Org. Lett.*, 2003, **5**, 4257; (*f*) D. S. Bose and R. K. Kumar, *Tetrahedron Lett.*, 2006, **47**, 813; (*g*) A. Walser, T. Flyll and R. T. Fryer, *J. Heterocycl. Chem.*, 1975, **12**, 737; (*h*) A. Arcadi, M. Chiarini, S. D. Giuseppe and F. Marinelli, *Synlett*, 2003, 203; (*i*) J. S. Yadav, B. V. S. Reddy and P. Premlatha, *Synlett*, 2004, 963; (*j*) K. Mogilaih and C. S. Reddy, *Synth. Commun.*, 2003, **33**, 3131.

13 (*a*) M. Narasimhulu, T. Srikanth Reddy, K. Chinni Mahesh, P. Prabhakar, C. Bhujanga Rao and Y. Venkateswarlu, *J. Mol. Catal. A: Chem.*, 2007, **266**, 114; (*b*) M. Dabiri, S. C. Azimi and A. Bazgir, *Monatsh. Chem.*, 2007, **138**, 659.

14 J. Wu, H.-G. Xia and K. Gao, *Org. Biomol. Chem.*, 2006, **4**, 126.

15 (*a*) C. S. Cho and W. X. Ren, *J. Organomet. Chem.*, 2007, **692**, 4182 and the ref. cited therein; (*b*) C. S. Cho, W. X. Ren and N. S. Yoon, *J. Mol. Catal. A: Chem.*, 2009, **299**, 117.

16 (*a*) S. S. Palimkar, S. A. Siddiqui, T. Daniel, R. J. Lahoti and K. V. Srinivasan, *J. Org. Chem.*, 2003, **68**, 9371; (*b*) J. Akbari, A. Heydari, H. R. Kalhor and S. A. Kohan, *J. Comb. Chem.*, 2010, **12**, 137; (*c*) G. Karthikeyan and P. T. Perumal, *J. Heterocycl. Chem.*, 2004, **41**, 1039; (*d*) T. Zhou, J. L. Lin and Z. C. Chen, *Lett. Org. Chem.*, 2008, **5**, 47; (*e*) M. Dabiri, P. Salehi, M. Baghbanzadeh and M. S. Nikcheh, *Tetrahedron Lett.*, 2008, **49**, 5366.

17 (*a*) B. Perio, M.-J. Dozias, P. Jacquault and J. Hamelin, *Tetrahedron Lett.*, 1997, **38**, 7867; (*b*) P. Goncalo, C. Roussel, J. M. Melot and J. Vebrel, *J. Chem. Soc., Perkin Trans. 2*, 1999, 2111; (*c*) S. Paul, M. Gupta, R. Gupta and A. Loupy, *Tetrahedron Lett.*, 2001, **42**, 3827; (*d*) C. S. Jia, Z. Zhang, S. J. Tu and G. W. Wang, *Org. Biomol. Chem.*, 2006, **4**, 104.

18 D. R. Sliskovic, J. A. Picard, W. H. Roark, B. D. Roth, E. Ferguson, B. R. Krause, R. S. Newton, C. Sekerke and M. K. Shaw, *J. Med. Chem.*, 1991, **34**, 367.

19 (*a*) G. W. Wang, C. S. Jia and Y. W. Dong, *Tetrahedron Lett.*, 2006, **47**, 1059; (*b*) M. A. Zolfigol, P. Salehi, A. Ghaderi and M. Shiri, *Catal. Commun.*, 2007, **8**, 1214; (*c*) S. Ghassamipour and A. R. Sardarian, *Tetrahedron Lett.*, 2009, **50**, 514; (*d*) M. A. Zolfigol, P. Salehi, A. Ghaderi, M. Shiri and Z. Tanbakouchian, *J. Mol. Catal. A: Chem.*, 2006, **259**, 253; (*e*) B. P. Bandgar, P. E. More and V. T. Kamble, *J. Chinese Chem. Soc.*, 2008, **55**, 947; (*f*) L. Zhang and J. Wu, *Adv. Synth. Catal.*, 2007, **349**, 1047.

20 (*a*) N. Paul and S. Muthusubramanian, *Tetrahedron Lett.*, 2011, **52**, 3743, DOI: 10.1016/j.tetlet.2011.05.046; (*b*) J. Nakayama, T. Konishi, A. Ishii and M. Hoshino, *Bull. Chem. Soc. Jpn.*,

1989, **62**, 2608; (*c*) H. Singh and C. S. Gandhi, *Synth. Commun.*, 1979, **9**, 569.
21 J. Nakayama, S. Iida, Y. Sugihara and A. Ishii, *J. Sulfur Chem.*, 2004, **25**, 13.
22 The filtrate of the reaction between diphenacyl sulfide and aminobenzophenone is taken in an RB flask and to this a fresh mixture of starting materials **2a** and **1** (1 : 2 molar ratio) are added and refluxed for two hours. The product **3a** is separated by recrystallisation and yield is calculated.
23 Crystallographic data (excluding structure factors) for compounds **3c**, **3h** and **5e** in this letter have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication numbers CCDC 824667, 827881 and 827882.
24 (*a*) H. Tabata, H. Suzuki, K. Akiba, H. Takahashi and H. Natsugari, *J. Org. Chem.*, 2010, **75**, 5984; (*b*) K. Undheim, J. Efskind and G. Beate Hoven, *Pure Appl. Chem.*, 2003, **75**, 279; (*c*) B. Jauk, T. Pernat and C. Oliver Kappe, *Molecules*, 2000, **5**, 227; (*d*) H. Saneyoshi, S. Mazzini, A. Avino, G. Portella, C. Gonzalez, M. Orozco, V. E. Marquez and R. Eritja, *Nucleic Acids Res.*, 2009, **37**, 5589.
25 M. J. S. Dewar, E. G. Zoebisch, E. F. Healy and J. J. P. Stewart, *J. Am. Chem. Soc.*, 1985, **107**, 3902.