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Short Report

NH_4Cl-CH_3OH: an Efficient, Acid- and Metal-Free Catalyst System for the Synthesis of Quinoxalines

Hossein Reza Darabi,* Fatemeh Tahoori, Kioumars Aghapoor, Fatemeh Taala and Farshid Mohsenzadeh

Chemistry & Chemical Engineering Research Center of Iran, Pajoohesh Blvd., km 17, Karaj Hwy, Tehran 14968-13151, Iran

A condensação direta de benzeno-1,2-diaminas (4-R-Ph-$(NH_2)_2$, onde R = H, Me, Cl e NO_2) e 1,2-dicarbonil (R'-CO-CO-R', onde R' = Ph, 4-MeO-Ph e Me) foi realizada com excelentes rendimentos (95-100%) usando (NH_4Cl-CH_3OH) como sistema catalítico brando, eficiente, de boa relação custo-benefício, fácil obtenção, isento de ácido e de metal e ambientalmente amigável, a temperatura ambiente. O procedimento pode ser realizado para diversas quinoxalinas e a natureza do grupo funcional no anel aromático das 1,2-diaminas exerce uma forte influência no tempo e rendimento da reação. A eficiência da condensação pode ser regulada também pela quantidade de catalisador e tempo de reação.

The direct condensation of various benzene-1,2-diamines [4-R-Ph-$(NH_2)_2$, where R = H, Me, Cl and NO_2] and 1,2-dicarbonyl compounds (R'-CO-CO-R', where R' = Ph, 4-MeO-Ph and Me) has been successfully achieved mostly in excellent yields (95-100%) using (NH_4Cl-CH_3OH) as a mild, efficient, cost-effective, readily available, acid-free, metal-free and eco-friendly catalyst system at room temperature. The procedure can be performed for a broad scope of quinoxalines, however, the nature of the functional group on the aromatic ring of 1,2-diamine exerts a strong influence on the time and the reaction yield. The condensation efficiency could be further regulated by the amount of catalyst and reaction time.

Keywords: quinoxalines, ammonium chloride-methanol, eco-friendly catalyst system, room temperature

Introduction

Among the various classes of nitrogen containing heterocyclic compounds, quinoxalines are important components of several pharmacologically active compounds associated with a wide spectrum of biological activities ranging from antihelmintic and anticancer to antimicrobial, antifungal, antidepressant, antibacterial and anti-inflammatory activities.[1] Although rarely described in nature, synthetic quinoxaline ring is a part of a number of antibiotics which are known to inhibit the growth of Gram-positive bacteria and are also active against various transplantable tumors.[2] Moreover, they are well known for their application in dyes,[3] efficient electroluminescent materials,[4] organic semiconductors,[5] building blocks for the synthesis of anion receptors,[6] cavitands,[7] dehydroannulenes[8] and DNA cleaving agents.[9]

In general, these compounds could be achieved via the double condensation of arene-1,2-diamines with 1,2-dicarbonyl compounds in organic solvents for 2-12 h under refluxing conditions with 34-85% yields.[10] From the synthesis standpoint, the traditional processes generally require high reaction temperature, strong acidic media, and mostly long reaction time.

Recent heating procedures have been reported in the literature for the synthesis of quinoxaline derivatives, using microwave,[11] classical[12] or ball-mill heating.[13] In contrast, many improved methods have been reported for the synthesis of quinoxalines at room temperature using catalytic amount of variety of molecular iodine,[14,15] acids,[16,17] and metal precursors.[18-20]

In a particular case, Brønsted-acidic task-specific ionic liquids (TSILs) were used as mild and green catalysts for the synthesis of quinoxaline derivatives, while the catalyst is not commercially available and a further step for its preparation is required.[21]

Despite the broad choice of options, most of the existing methodologies suffer from disadvantages such as unsatisfactory product yields, critical product

*e-mail: darabi@ccerci.ac.ir; r_darabi@yahoo.com

isolation procedures, colored products demanding further recrystalization, expensive and detrimental metal precursors, and procedures with limited activity, *i.e.* without being applicable to the entire family of quinoxaline derivatives. Due to these problems, the search for the new readily available and green catalysts is still being actively pursued.

The development of cost-effective and environmentally benign catalytic systems is one of the main themes of contemporary organic synthesis. Ammonium chloride (NH_4Cl) is a very inexpensive, eco-friendly and easily available catalyst. It has been reported as catalyst for synthesis of various organic compounds. It has effectively promoted Ugi four-component reactions[22] and four-component synthesis of pyrrolo[3,4-b]pyridinones.[23] Moreover NH_4Cl is effectively used as catalyst for aliphatic Claisen rearrangement,[24] reduction of azo compounds to their corresponding hydrazines,[25] reduction of nitrophenols in aqueous media[26] and under ultrasound,[27] reductive cleavage of azo compounds,[28] Biginelli synthesis of 3,4-dihydropyrimidinones,[29] the one-pot synthesis of diindolylmethanes,[30] and the thia-Michael addition reaction.[31]

The aim of this study is to utilize an eco-friendly NH_4Cl–CH_3OH system for the synthesis of quinoxaline derivatives at ambient temperature using ammonium chloride as an acid- and metal-free catalyst and methanol as the benign reaction medium in medicinal chemistry.[32]

Results and Discussion

In continuation of our interest on the development of efficient, practical and eco-friendly procedures for the synthesis of condensed benzo[N,N]-heterocyclic compounds,[33-35] we herein wish to introduce NH_4Cl-CH_3OH as a mild and effective catalyst system for the synthesis of quinoxaline derivatives. In general, this method affords the products in excellent yields and avoids the problems associated with catalyst cost, handling and safety.

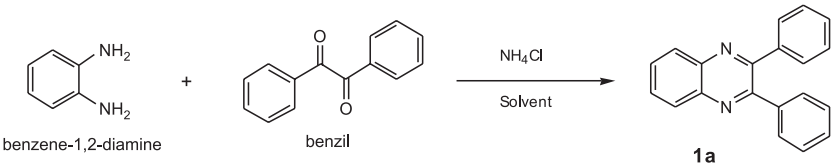
We first studied a reaction between benzene-1,2-diamine and benzil by screening the reaction conditions. In order to determine the optimum conditions, we started by examining the influence of the reaction time and the solvent effect at room temperature (Table 1). After screening different solvents, it was found that NH_4Cl-catalyzed synthesis of quinoxaline **1a** is not only faster, but also results in excellent yields in MeOH than in other solvents (Table 1).

The effect of the amounts of NH_4Cl on the yield of condensation reaction in MeOH was then explored using the same model reaction. As shown in Table 2, the various amounts of NH_4Cl gave quantitative yield of product while the times for the completion of the reaction are within 7-36 min (Table 2, entries 1-4).

According to literature,[10,33,36] the electron-withdrawing groups on the aromatic ring of arene-1,2-diamines have negative influence on the reaction yield. This fact led us to investigate on the molar ratio of the catalyst to 4-chlorobenzene-1,2-diamine in order to develop reliable results.

The results of the reaction between 4-chlorobenzene-1,2-diamine and benzil are shown in Table 3. The increased loading of the catalyst from 5 to 50 mol% at an agreed time (1 h) clearly showed that the higher amount of the catalyst increased the yield of **1d** noticeably (Table 3, entries 1-4). It appeared that a 50 mol% of NH_4Cl in MeOH is the suitable choice for the general reaction.

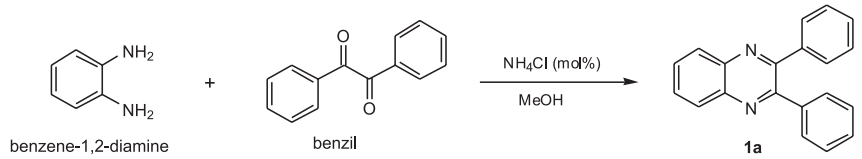
Table 1. Synthesis of 2,3-diphenylquinoxaline (**1a**) in the presence of a catalytic amount of NH_4Cl (10 mol%) in various solvents



benzene-1,2-diamine benzil **1a**

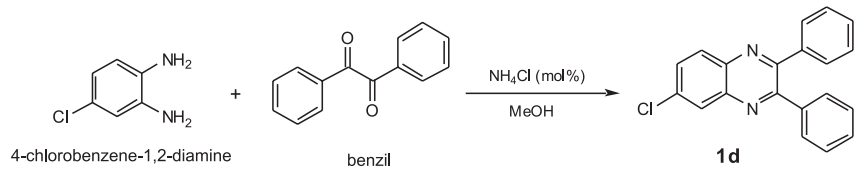
Entry	T / ºC	time	Solvent	Isolated Yield / (%)
1	25	20 min	CH_3OH	100
2	25	1 h	CH_3CH_2OH	92
3	25	3 h	H_2O	75
4	25	3 h	C_6H_{14}	65
5	25	3 h	CH_2Cl_2	62
6	25	3 h	$ClCH_2CH_2Cl$	30
7	25	3 h	CH_3CN	94

Table 2. Optimization of the molar ratio of NH_4Cl to benzene-1,2-diamine for preparing 2,3-diphenylquinoxaline (**1a**) at room temperature



Entry	NH_4Cl/%	Solvent	time/min	Isolated Yield / (%)
1	50 mol	MeOH	7	100
2	20 mol	MeOH	16	100
3	10 mol	MeOH	20	100
4	5 mol	MeOH	36	100

Table 3. Optimization of the molar ratio of NH_4Cl to 4-chlorobenzene-1,2-diamine for preparing 6-chloro-2,3-diphenylquinoxaline (**1d**) at room temperature



Entry	NH_4Cl/%	Solvent	time / h	Isolated Yield / (%)
1	50 mol	MeOH	1	96
2	20 mol	MeOH	1	72
3	10 mol	MeOH	1	58
4	5 mol	MeOH	1	43

These excellent results led us to expand the generality of this catalyst to various substrates. We examined the reaction under optimized conditions and the results are summarized in Table 4. All of the products were characterized by ^1H NMR, ^{13}C NMR, and MS spectral analysis.

As shown in Table 4, a series of arene-1,2-diamines reacted with various 1,2-dicarbonyls at room temperature smoothly to afford a wide range of quinoxaline derivatives, mostly in excellent yields. The results show that the nature of the functional group on the aromatic ring of the substrate exerted a strong influence on the time and the reaction yield. In general, when R on benzene-1,2-diamine represents the electron-withdrawing groups such as chloro (Table 4, entries d, h, l) and nitro groups (Table 4, entries c, g, k), longer reaction time is required. The existence of electron-donating substituent R' such as methoxy on 1,2-dicarbonyls has also negative influence on the reaction rate (Table 4, entries e-h). Accordingly, it is expected that a reaction between 4-nitrobenzene-1,2-diamine and 4,4'-dimethoxy-benzil should give the low yield of product **1g** (Table 4, entry g). Use of 200 mol% of NH_4Cl, however, gave an improved yield of **1g** after 4 h reaction at room temperature.

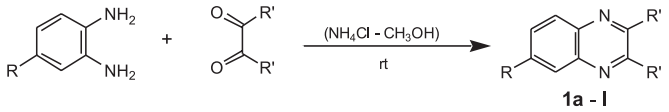
Our findings reflect the wide applicability and usefulness of the method (Table 4). Some previously reported data on reaction conditions and the yield of product for preparation of quinoxaline **1b** were compared with our results (Table 5). As one can see our results show a very good comparability with previously reported data with regard to yields and reaction times.

The remarkable efficiency of NH_4Cl–CH_3OH system can be explained by a better synergetic effect of NH_4Cl in its ionic form with MeOH. The proposed mechanism for NH_4Cl-catalyzed synthesis of quinoxalines may be visualized to occur via a sequence of reactions as depicted in Scheme 1. Ammonium chloride may activate the carbonyl compounds by hydrogen bonding to promote the reaction via the nucleophilic attack of amines.[30]

Conclusions

In summary, we have highlighted the potential of NH_4Cl-CH_3OH as a cheap, clean and non-toxic catalyst system for synthesis of quinoxalines from various 1,2-diketones and 1,2-diamines at ambient temperature. The attractive

Table 4. Synthesis of quinoxaline derivatives at room temperature using NH_4Cl–CH_3OH system



1a - l

Entry	R	R'	Product **1**	time	Yield / (%)[a,b]
a	H	Ph	2,3-diphenylquinoxaline	7 min	100
b	Me	Ph	6-methyl-2,3-diphenylquinoxaline	5 min	100
c	NO_2	Ph	6-nitro-2,3-diphenylquinoxaline	4 h	25 (66)[c] (95)[d]
d	Cl	Ph	6-chloro-2,3-diphenylquinoxaline	1 h	96
e	H	4-(MeO)-Ph	2,3-bis(4-methoxyphenyl)quinoxaline	1 h	95
f	Me	4-(MeO)-Ph	6-methyl-2,3-bis(4-methoxyphenyl)quinoxaline	40 min	94
g	NO_2	4-(MeO)-Ph	6-nitro-2,3-bis(4-methoxyphenyl)quinoxaline	4 h	5 (20)[c]
h	Cl	4-(MeO)-Ph	6-chloro-2,3-bis(4-methoxyphenyl)quinoxaline	2.5 h	96
i	H	Me	2,3-dimethylquinoxaline	5 min	100
j	Me	Me	6-methyl-2,3-dimethylquinoxaline	5 min	96
k	NO_2	Me	6-nitro-2,3-dimethylquinoxaline	4 h	97
l	Cl	Me	6-chloro-2,3-dimethylquinoxaline	35 min	97

[a]Yields refer to those of pure isolated products characterized by ^1H NMR, ^{13}C NMR and MS spectral analyses. [b]The reaction was carried out in the presence of NH_4Cl (50 mol%). [c]The reaction was carried out in the presence of NH_4Cl (200 mol%) within 4 h. [d]The reaction was carried out in the presence of NH_4Cl (200 mol%) within 24 h.

Table 5. Synthesis of quinoxaline **1b** at room temperature using different catalysts/solvents

Entry	Catalyst	Solvent	time	Yield / (%)[a]	Ref.
1	Iodine (10 mol%)	CH_3CN	5 min	95	14
2	Iodine (10 mol%)	DMSO	50 min	90	15
3	*o*-Iodoxybenzoic acid (1 mol%)	CH_3COOH	15 min	98	16
4	Montmorillonite K-10 (10% m/m)	H_2O	2.5 h	100	17
5	Cerium(IV) ammonium nitrate (5 mol%)	H_2O	10 min	90	18
6	Zn[(L)proline] (10 mol%)	CH_3COOH	5 min	96	19
7	Polyaniline-sulfate salt (5% m/m)	$ClCH_2CH_2Cl$	15 min	92	36
8	Sulfamic acid (5 mol%)	CH_3OH	5 min	100	33
9	Ammonium chloride (50 mol%)	CH_3OH	5 min	100	Table 4

[a]Isolated yield.

features of this simple procedure are the mild reaction conditions, mostly excellent yields, acid-free, metal-free, readily available and environmentally friendly system, all of which make it a useful and attractive strategy for the preparation of various quinoxaline derivatives.

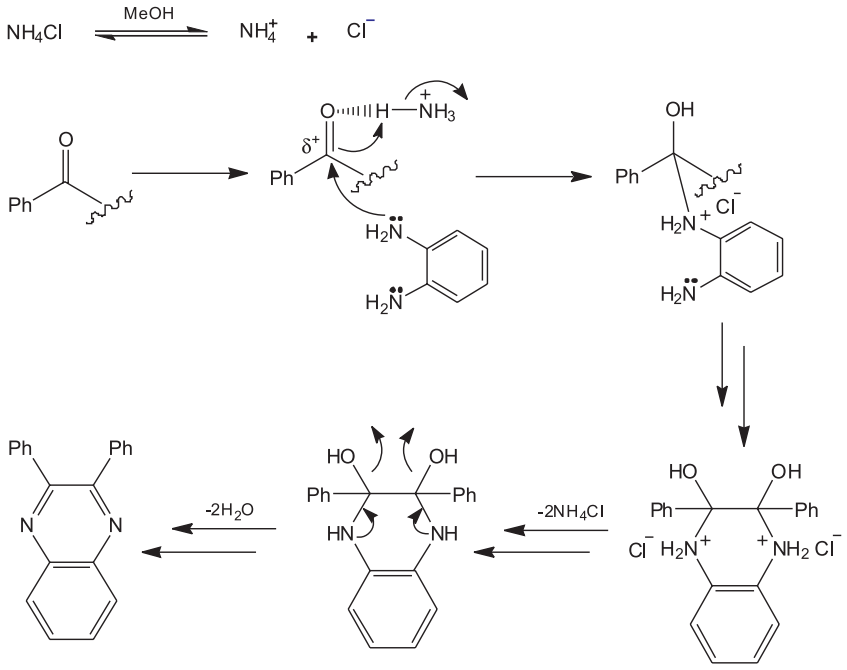
Experimental

Materials and methods

^1H and ^{13}C NMR spectra were recorded on a Bruker-500. All NMR samples were run in $CDCl_3$ and chemical shifts are expressed as ppm relative to internal Me_4Si. Mass spectra were obtained on a Fisons instrument. Column chromatography was carried out with the use of Merck Art. 7734 kieselgel 60, 70-230 mesh ASTM. Substrates are commercially available and used without further purification.

*General procedure for the preparation of quinoxaline derivatives **1a-h***

To a stirred solution of benzil or 4,4'-dimethoxy-benzil (1 mmol) in 5 mL methanol was added benzene-1,2-diamine (1.2 mmol) and ammonium chloride (50 mol%). The mixture was stirred at room temperature for an



Scheme 1. Proposed mechanism for NH_4Cl-catalyzed quinoxaline synthesis.

appropriate time (Table 4). After completion of the reaction (monitored by TLC), the reaction mixture was poured into water (20 mL) and the precipitated solid was collected by filtration and dried to afford the product **1**. To obtain pure samples for analytical measurements, a silica gel column chromatography was performed. The eluent for all samples is ethyl acetate/hexane (3:7 v/v), except for **1d** and **1h** that is hexane/dichloromethane (1:10 v/v). The identification of the isolated products was generally performed by ^{1}H NMR, ^{13}C NMR and MS spectral analyses.

*General procedure for the preparation of quinoxaline derivatives **1i**- **l***

To a stirred solution of butane-2,3-dione (1.3 mmol) in 5 mL methanol was added benzene-1,2-diamine (1 mmol) and ammonium chloride (50 mol%). The mixture was stirred at room temperature for an appropriate time (Table 4). The progress was monitored by TLC. The reaction mixture was washed with water (20 mL) and extracted by CH_2Cl_2 (3 × 10 mL). The organic phase was evaporated under reduced pressure and the pure product **1i**-**l** was obtained without any further purification.

Selected spectral data

*2,3-dimethylquinoxaline (**1i**)*

^{1}H NMR (500 MHz, $CDCl_3$): δ 2.78 (s, 6H), 7.70 (dd, 2H), 8.02 (dd, 2H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 23.76, 128.7, 129.2, 141.5, 153.9; MS (EI), *m/z* (rel. intensity %) 158 (M^+, 65), 116 (100), 76 (40), 50 (50).

*6-methyl-2,3-dimethylquinoxaline (**1j**)*

^{1}H NMR (500 MHz, $CDCl_3$): δ 2.60 (s, 3H), 2.75 (s, 6H), 7.53 (dd, 1H), 7.79 (s, 1H), 7.90 (d, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 22.1, 23.5, 23.6, 127.7, 128.2, 131.4, 139.5, 139.9, 141.6, 152.8, 153.7; MS (EI), *m/z* (rel. intensity %) 172 (M^+, 100), 130 (90), 89 (45), 50 (20).

*6-nitro-2,3-dimethylquinoxaline (**1k**)*

^{1}H NMR (500 MHz, $CDCl_3$): δ 2.82 (s, 3H), 2.83 (s, 3H), 8.12 (d, 1H), 8.46 (dd, 1H), 8.90 (d, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 23.7, 23.9, 122.8, 125.3, 130.3, 140.4, 144.1, 147.6, 156.7, 157.6; MS (EI), *m/z* (rel. intensity %) 203 (M^+, 100), 162 (30), 116 (50), 75 (15).

*6-chloro-2,3-dimethylquinoxaline (**1l**)*

^{1}H NMR (500 MHz, $CDCl_3$): δ 2.76 (s, 3H), 2.77 (s, 3H), 7.64 (dd, 1H), 7.93 (d, 1H), 8.00 (d, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 23.5, 23.6, 127.8, 130.0, 130.2, 134.8, 140.0, 141.8, 154.2, 154.9; MS (EI), *m/z* (rel. intensity %) 192 (M^+, 70), 151 (100), 110 (60), 75 (65).

Supplementary Information

^{1}H NMR and ^{13}C NMR of the selected spectral data mentioned above are available free of charge at http://jbcs.sbq.org.br, as PDF file.

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NH_4Cl-CH_3OH: An Efficient, Acid- and Metal-Free Catalyst System for the Synthesis of Quinoxalines

Hossein Reza Darabi,* Fatemeh Tahoori, Kioumars Aghapoor, Fatemeh Taala and Farshid Mohsenzadeh

Chemistry & Chemical Engineering Research Center of Iran, Pajoohesh Blvd., km 17, Karaj Hwy, Tehran 14968-13151, Iran

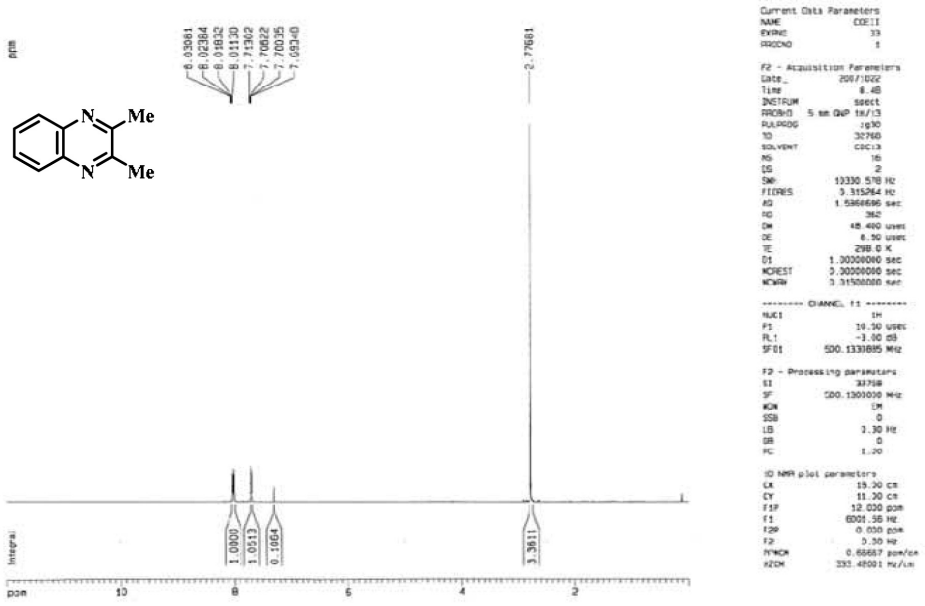

Figure S1a. ^{1}H NMR of **1i** (500 MHz, $CDCl_3$).

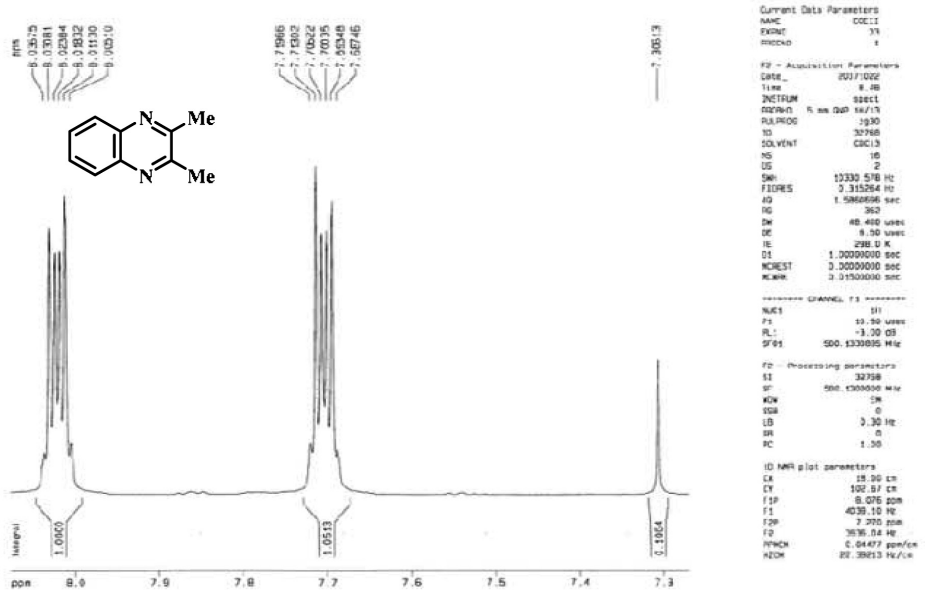

Figure S1b. ^{1}H NMR of **1i** (500 MHz, $CDCl_3$).

*e-mail: darabi@ccerci.ac.ir; r_darabi@yahoo.com

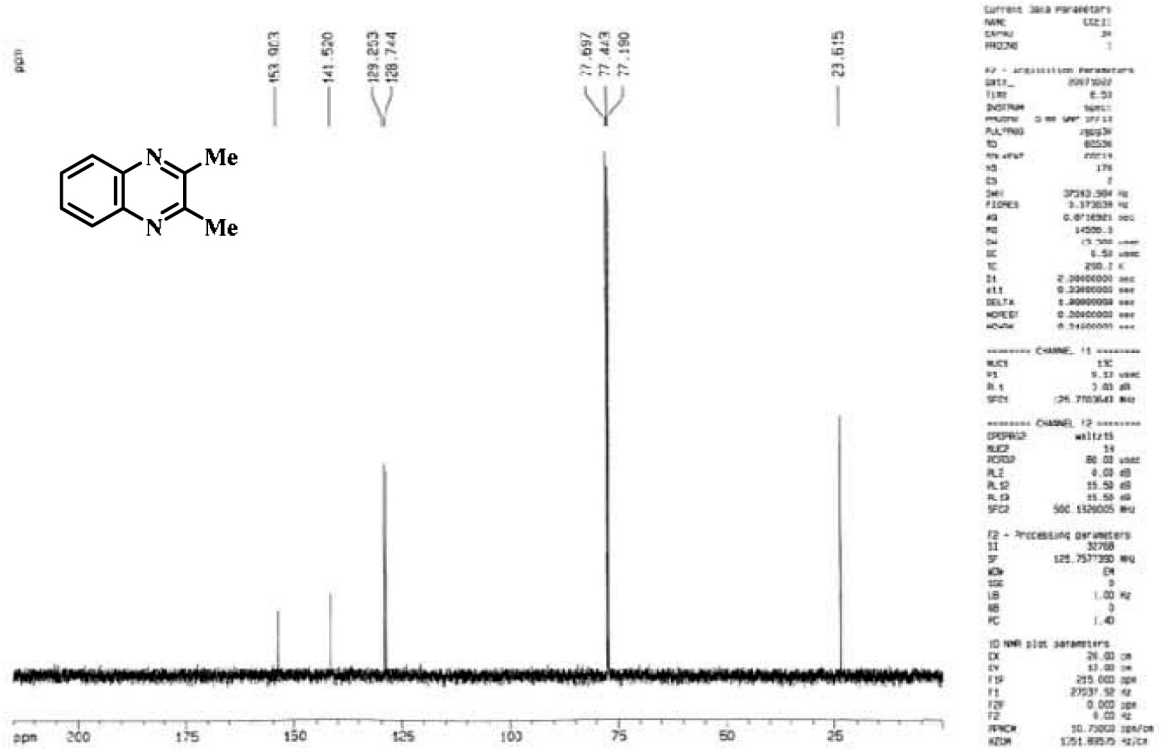

Figure S2a. ^{13}C NMR of **1i** (125 MHz, $CDCl_3$).

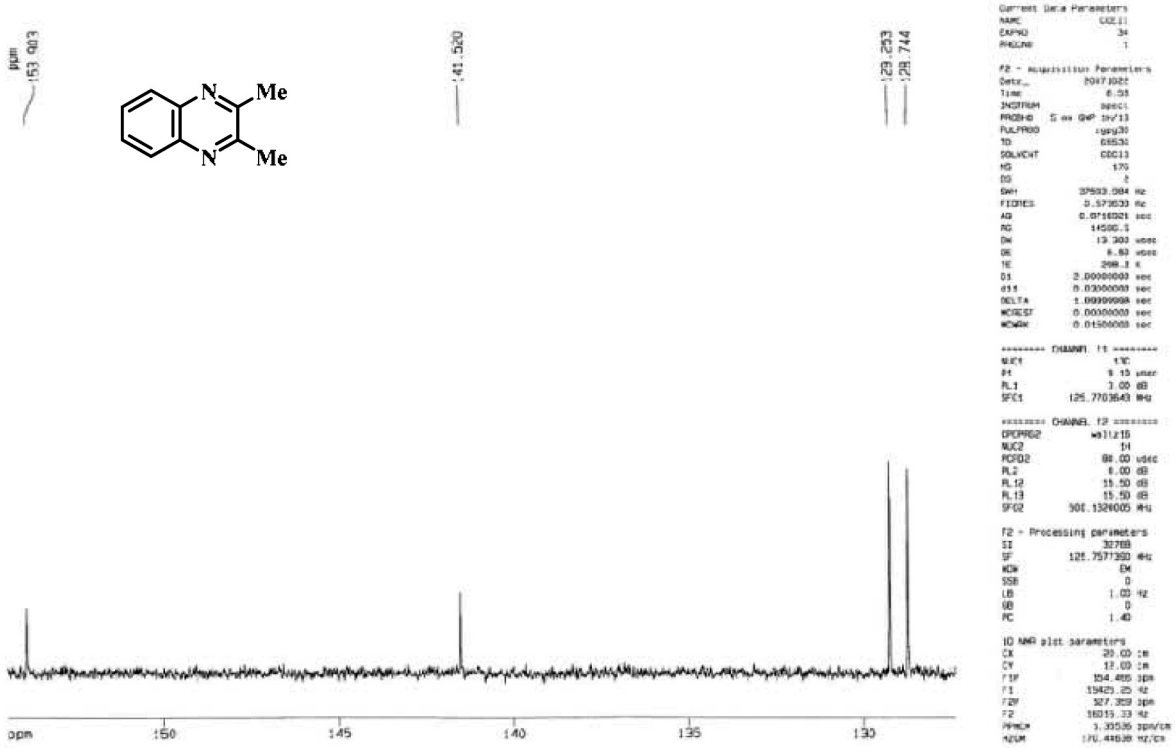

Figure S2b. ^{13}C NMR of **1i** (125 MHz, $CDCl_3$).

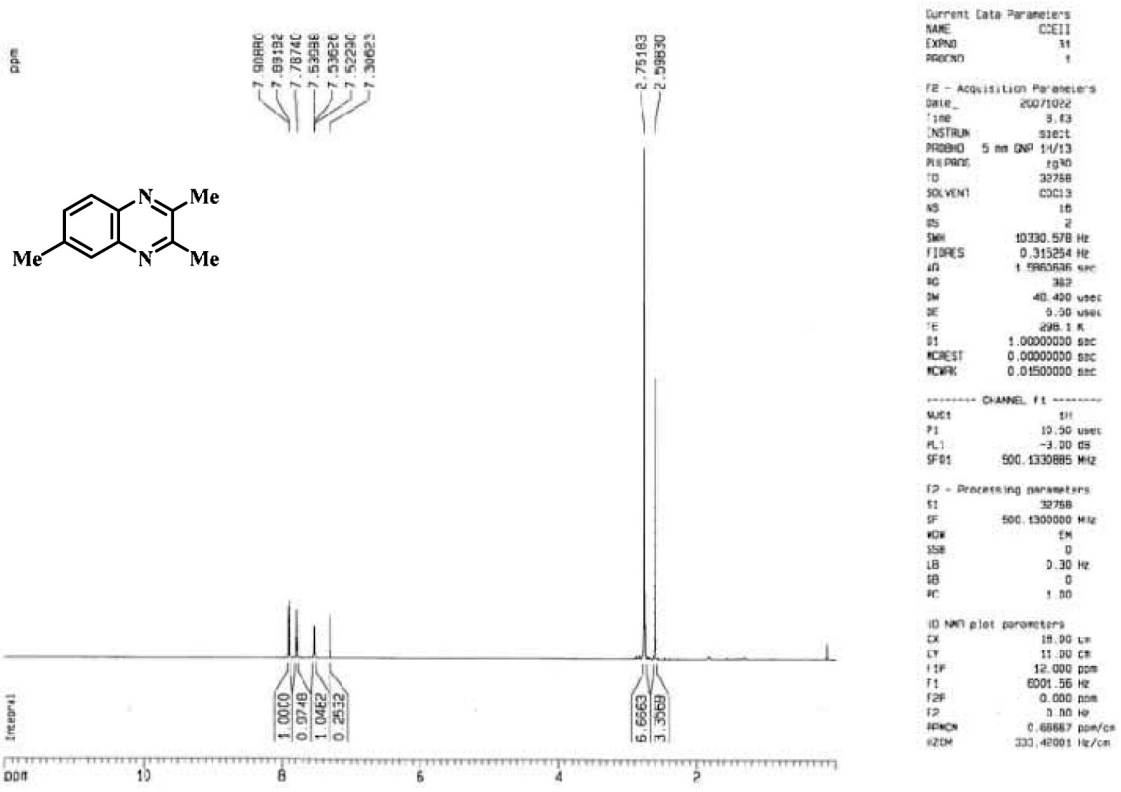

Figure S3a. ^{1}H NMR of **1j** (500 MHz, $CDCl_3$).

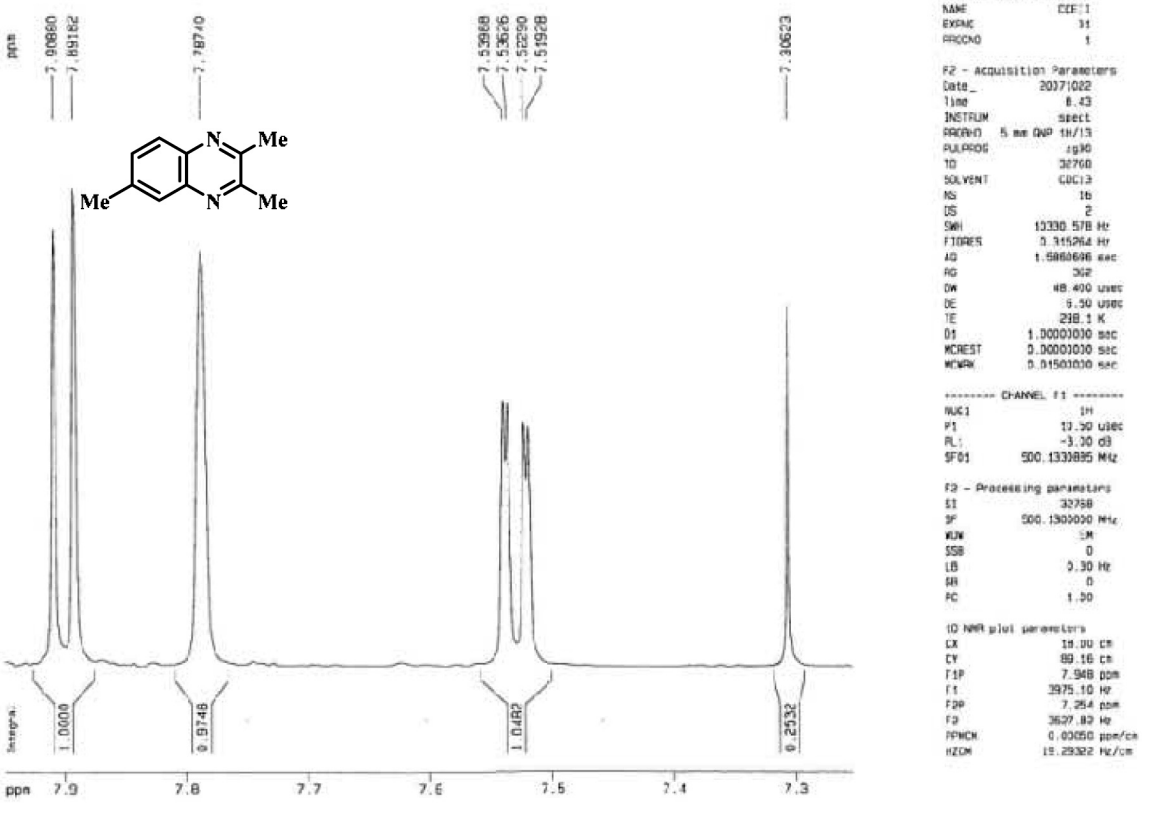

Figure S3b. ^{1}H NMR of **1j** (500 MHz, $CDCl_3$).

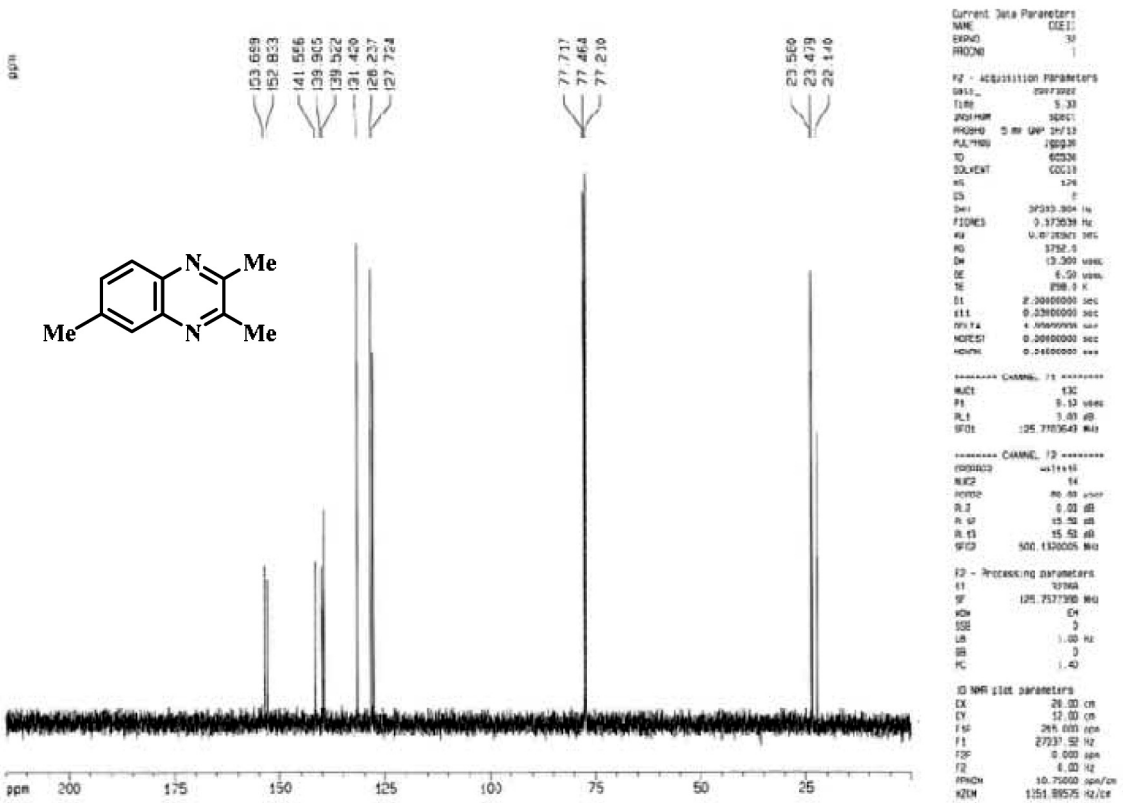

Figure S4a. ^{13}C NMR of **1j** (125 MHz, $CDCl_3$).

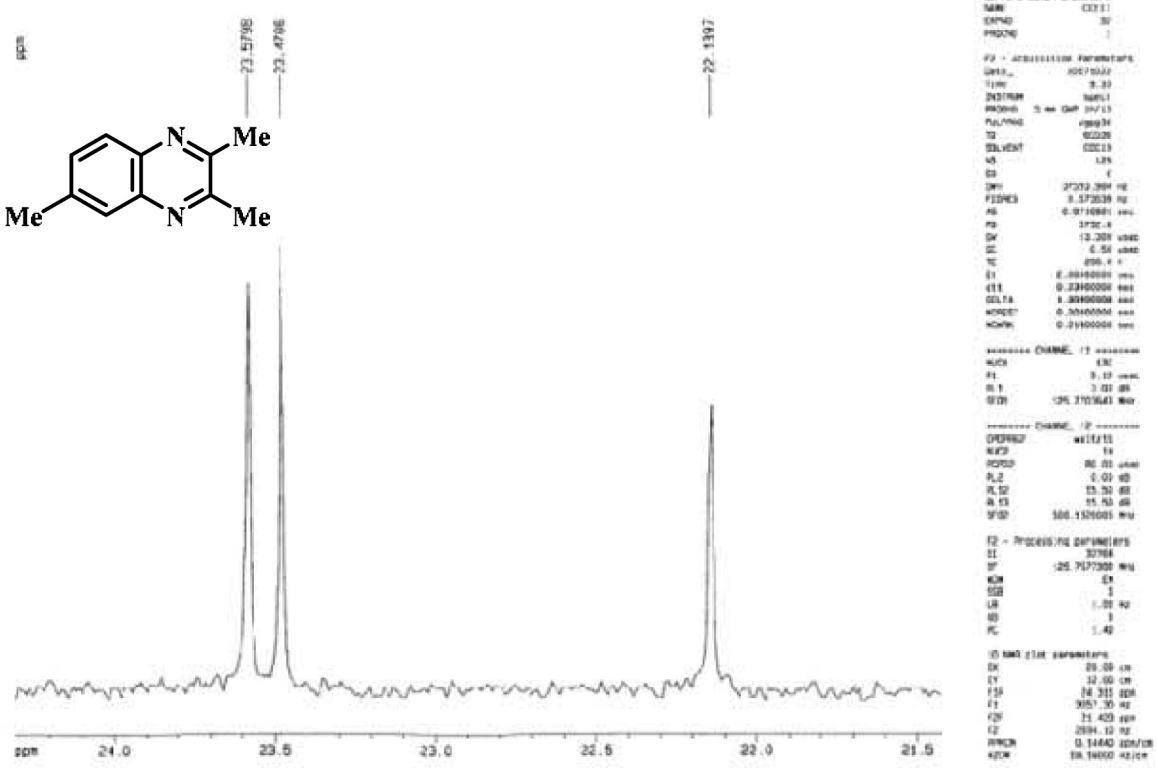

Figure S4b. ^{13}C NMR of **1j** (125 MHz, $CDCl_3$).

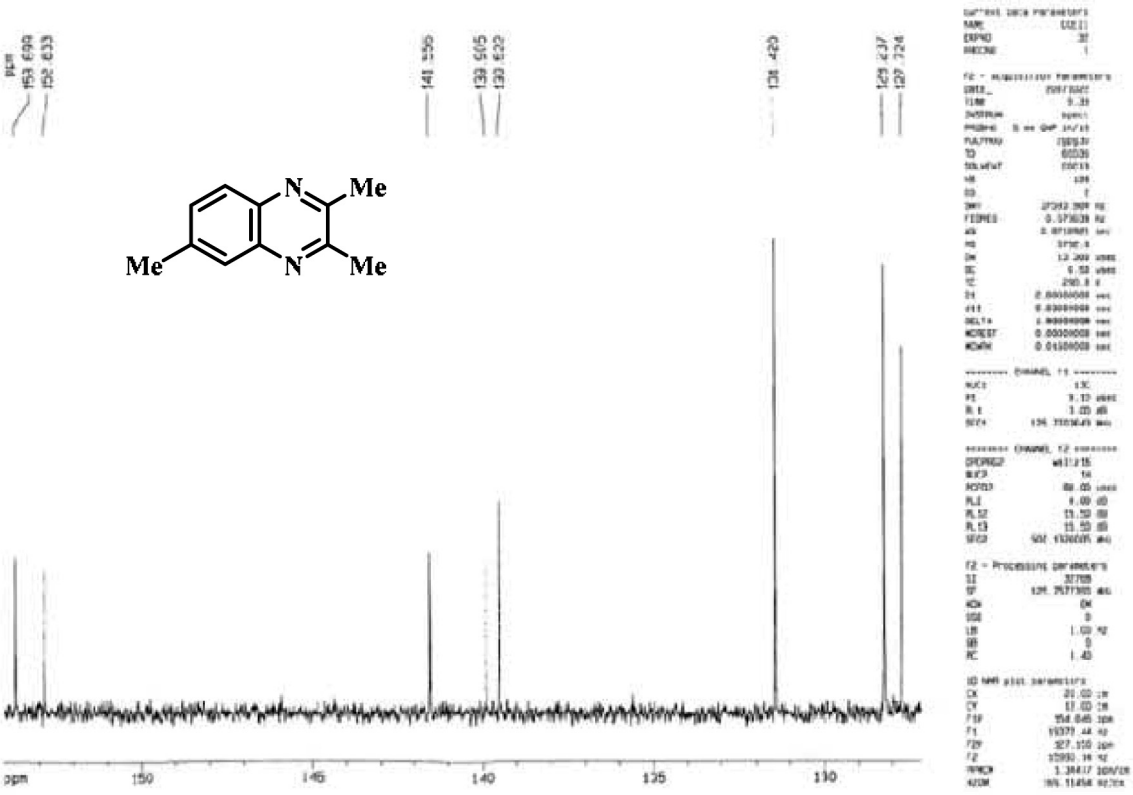

Figure S4c. ^{13}C NMR of **1j** (125 MHz, $CDCl_3$).

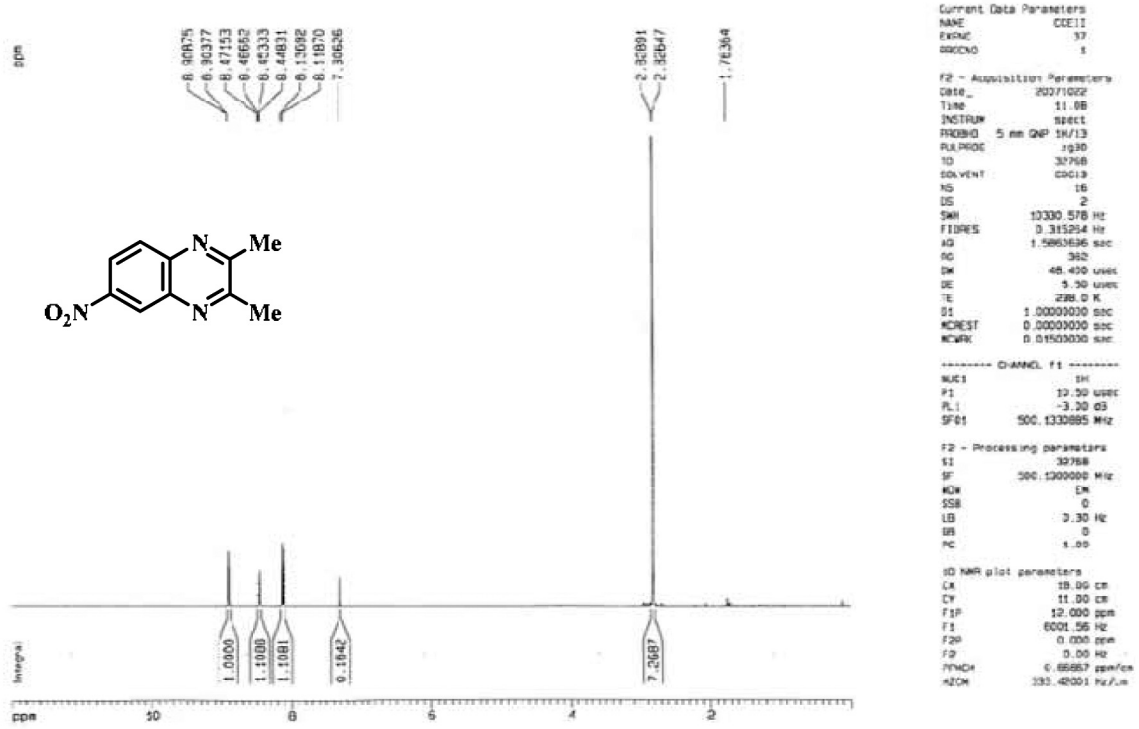

Figure S5a. ^{1}H NMR of **1k** (500 MHz, $CDCl_3$).

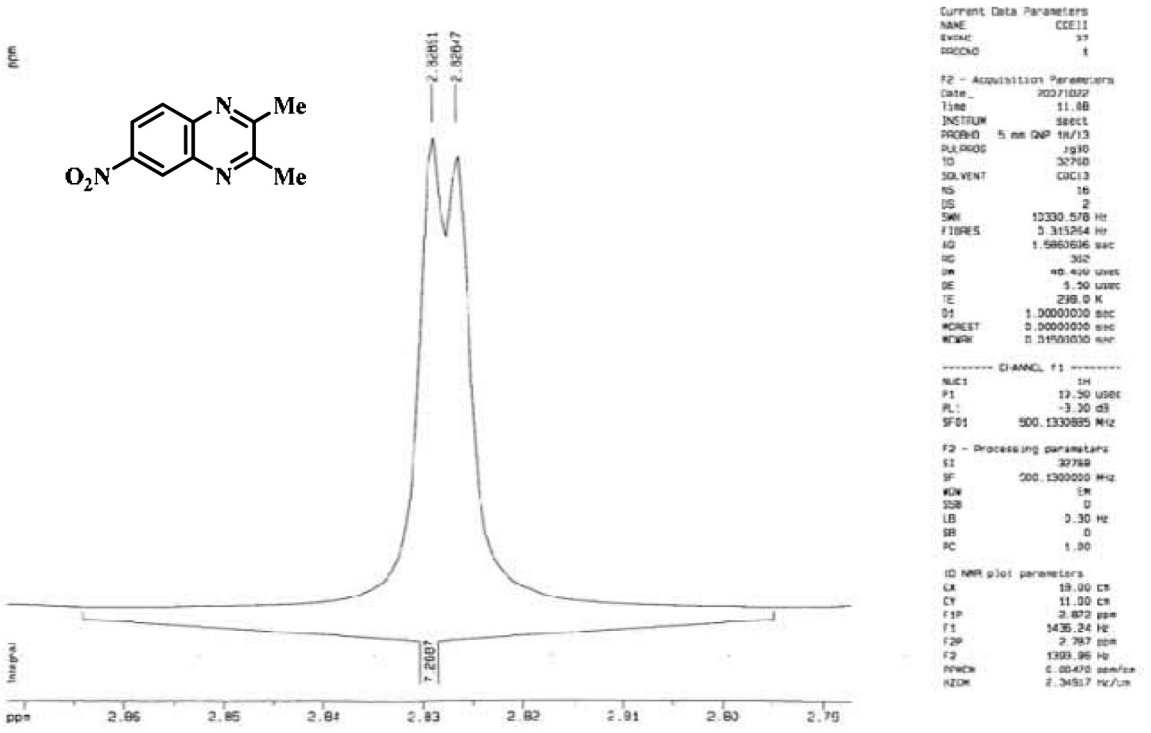

Figure S5b. ^{1}H NMR of **1k** (500 MHz, $CDCl_3$).

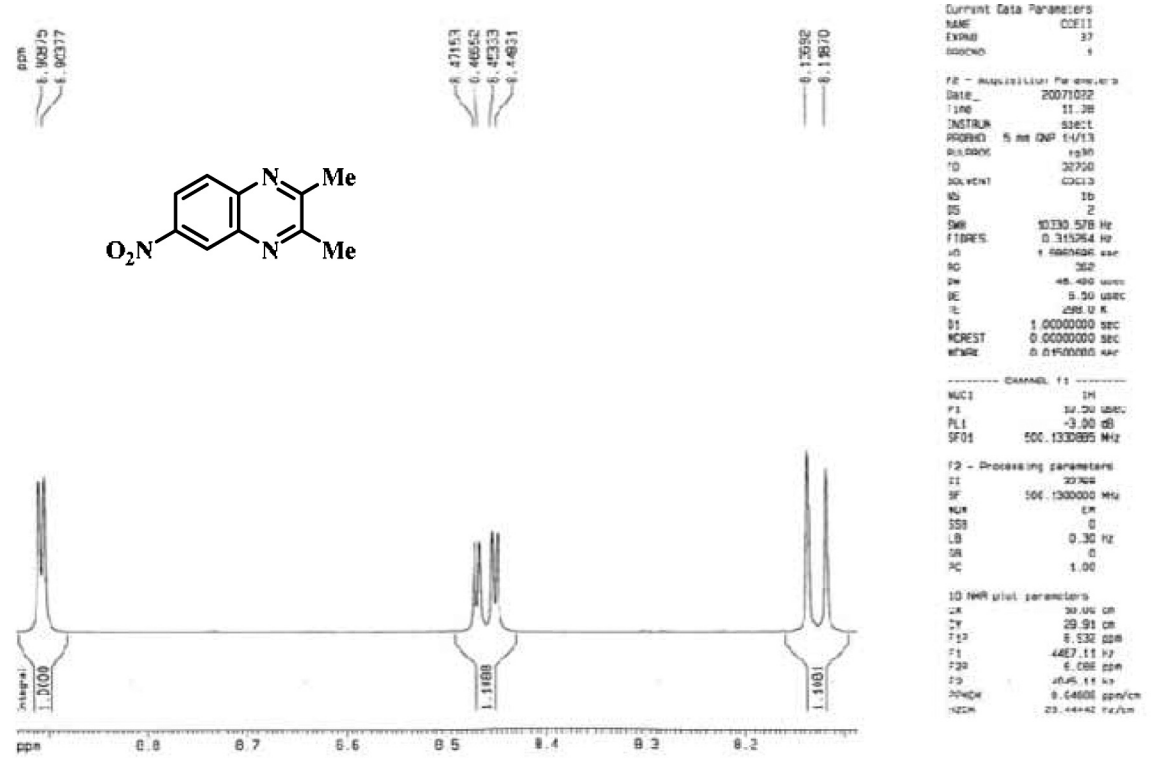

Figure S5c. ^{1}H NMR of **1k** (500 MHz, $CDCl_3$).

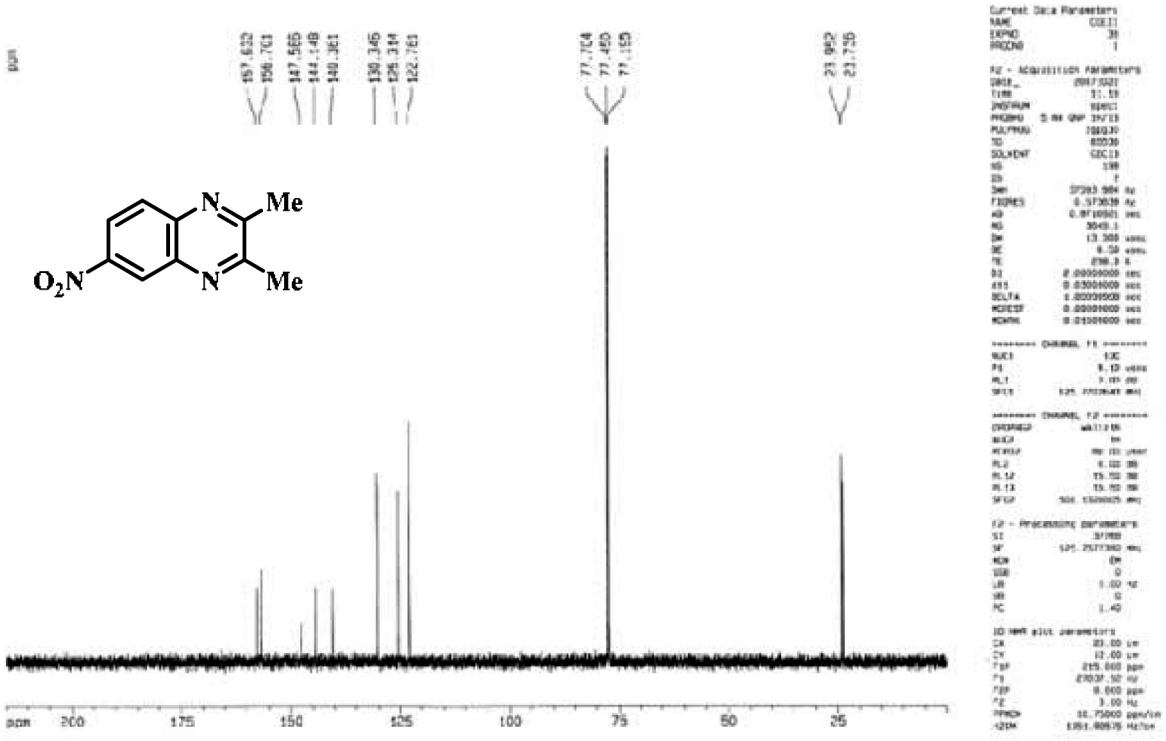

Figure S6a. ^{13}C NMR of **1k** (125 MHz, $CDCl_3$).

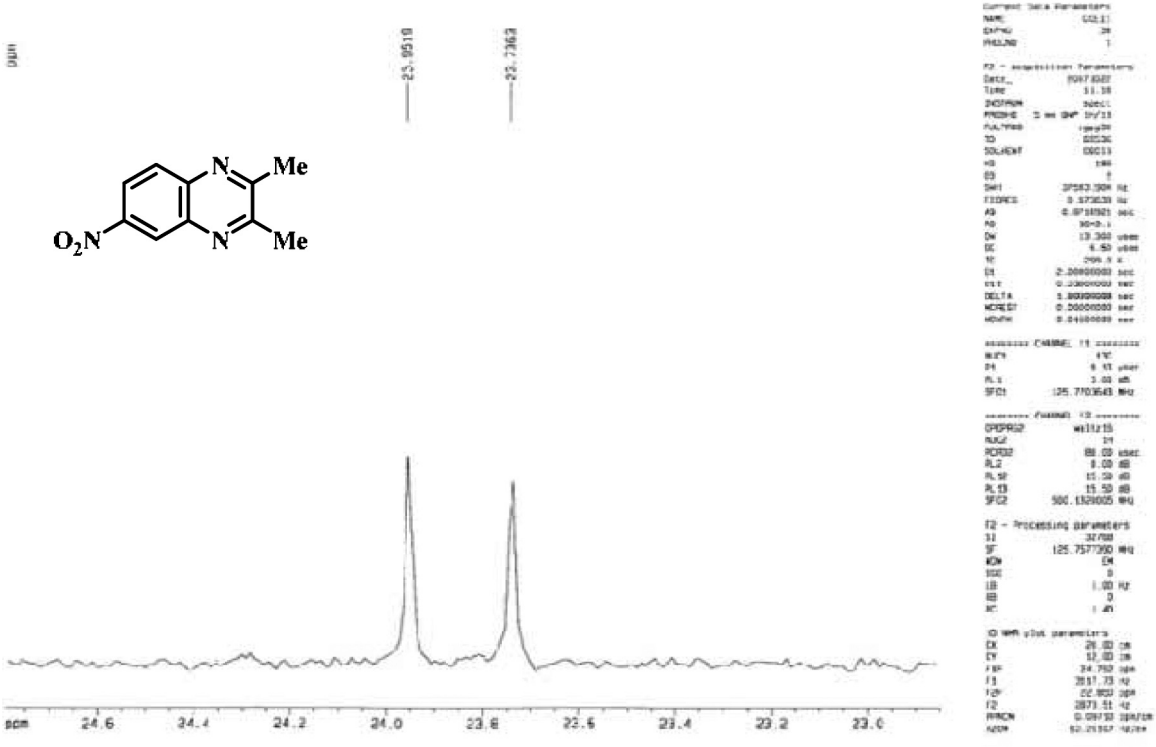

Figure S6b. ^{13}C NMR of **1k** (125 MHz, $CDCl_3$).

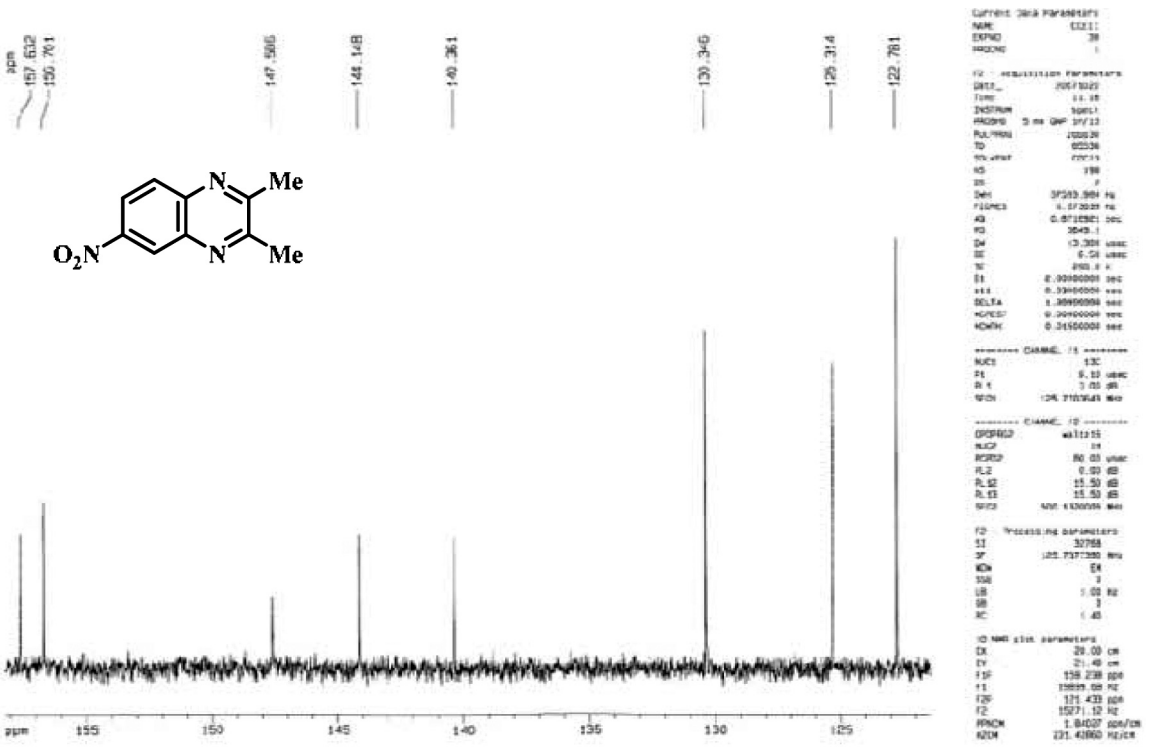

Figure S6c. ^{13}C NMR of **1k** (125 MHz, $CDCl_3$).

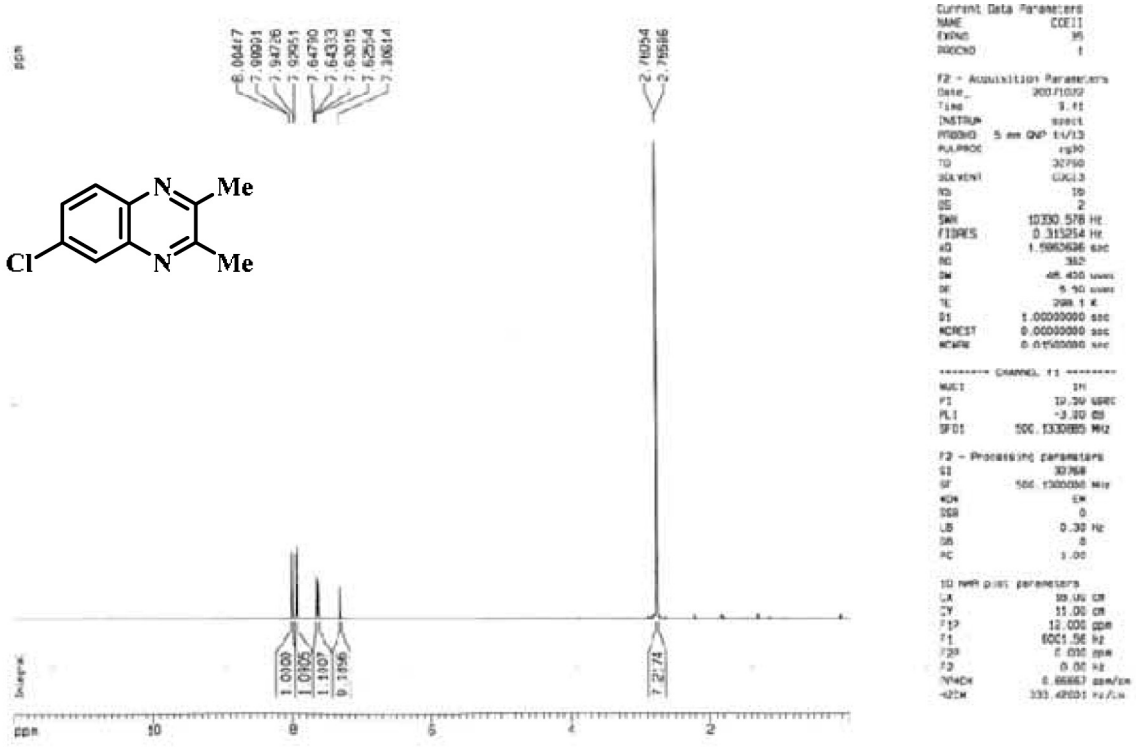

Figure S7a. ^1H NMR of **1l** (500 MHz, $CDCl_3$).

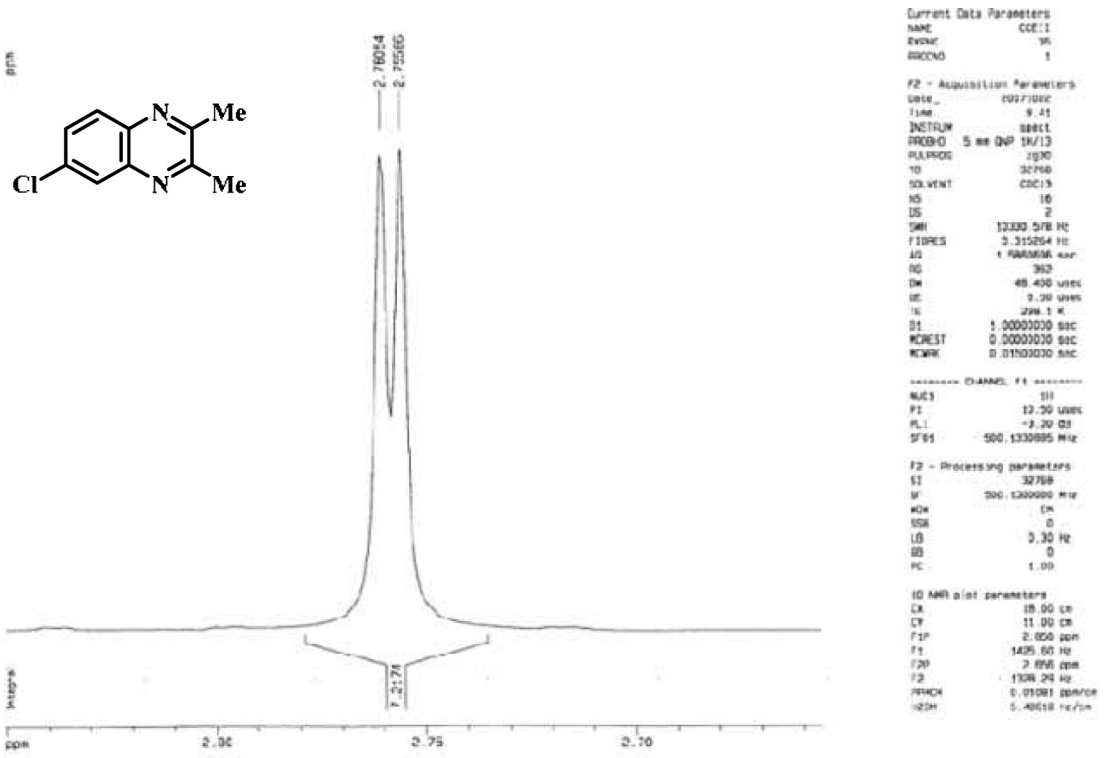

Figure S7b. ^{1}H NMR of **1l** (500 MHz, $CDCl_3$).

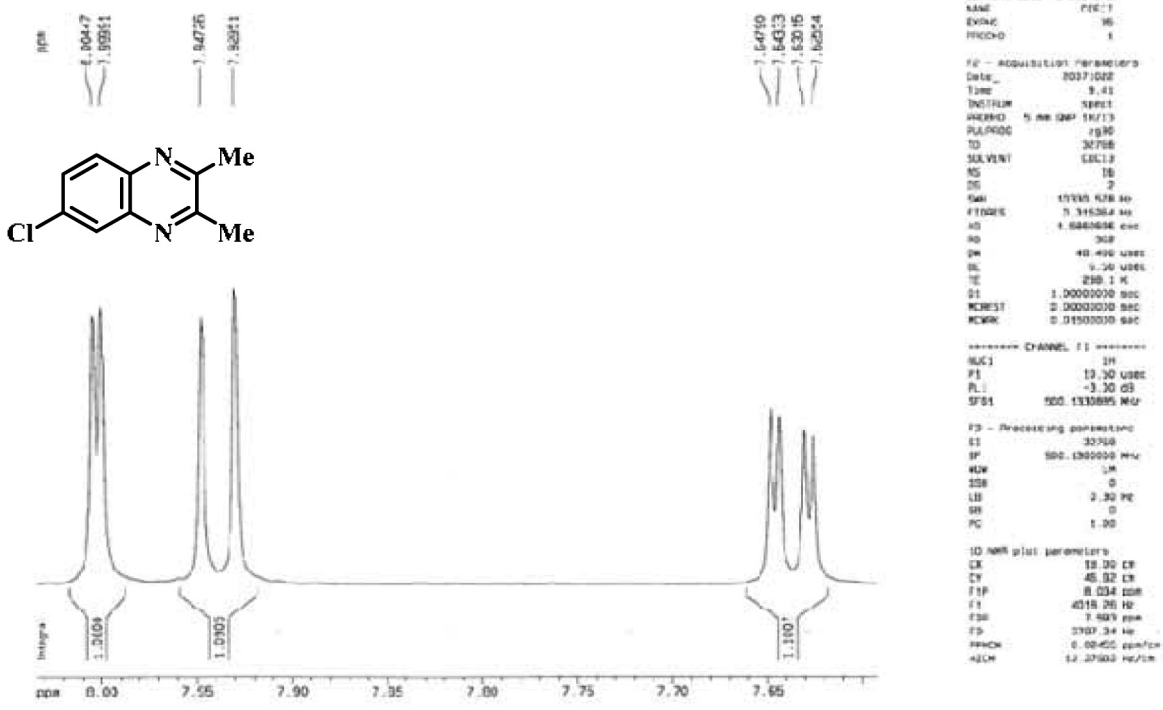

Figure S7c. ^{1}H NMR of **1l** (500 MHz, $CDCl_3$).

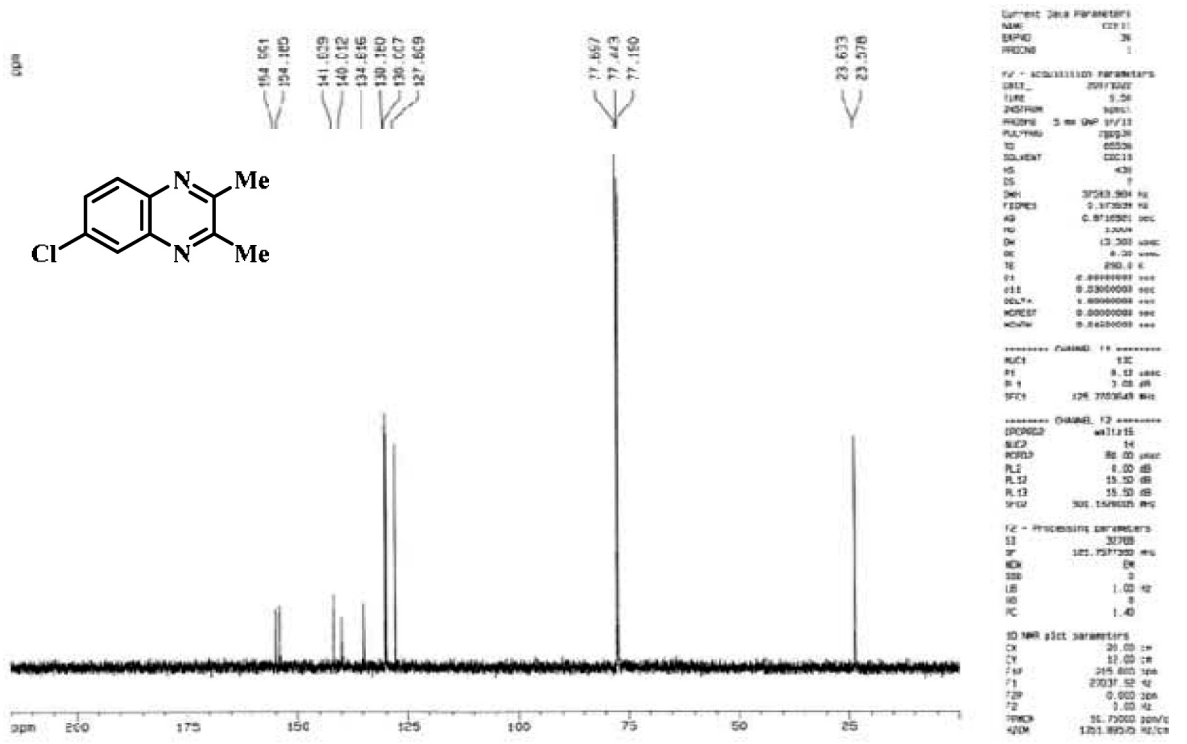

Figure S8a. ^{13}C NMR of **1l** (125 MHz, $CDCl_3$).

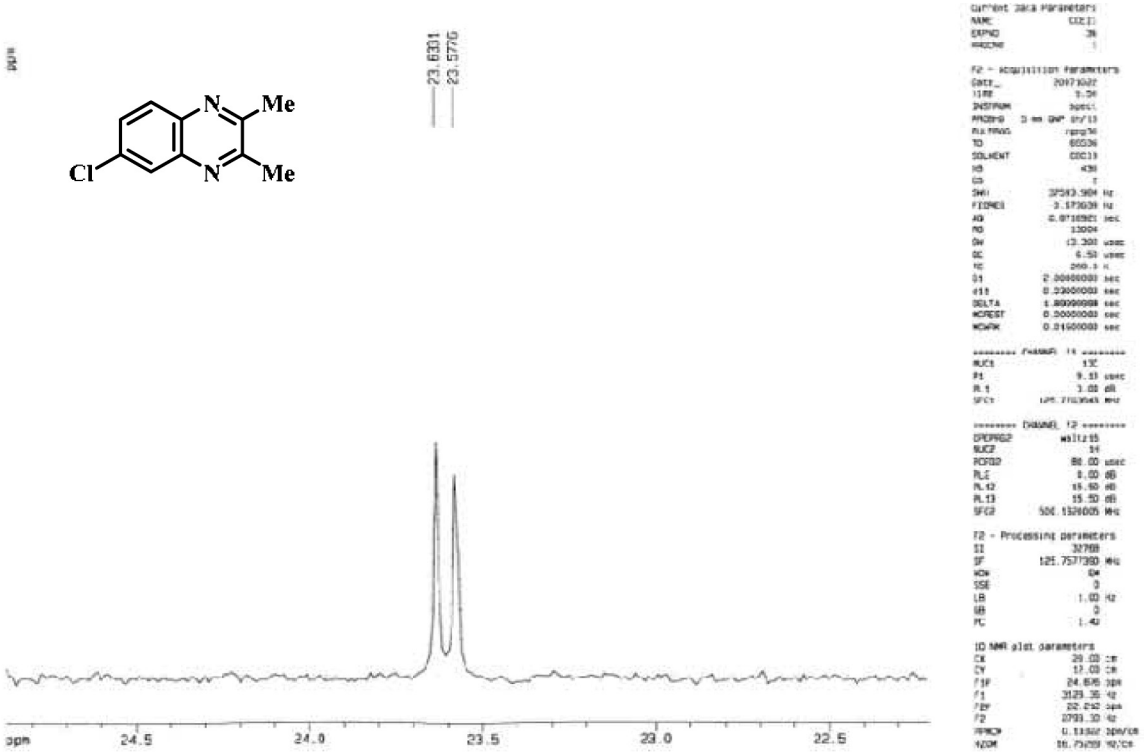

Figure S8b. ^{13}C NMR of **1l** (125 MHz, $CDCl_3$).

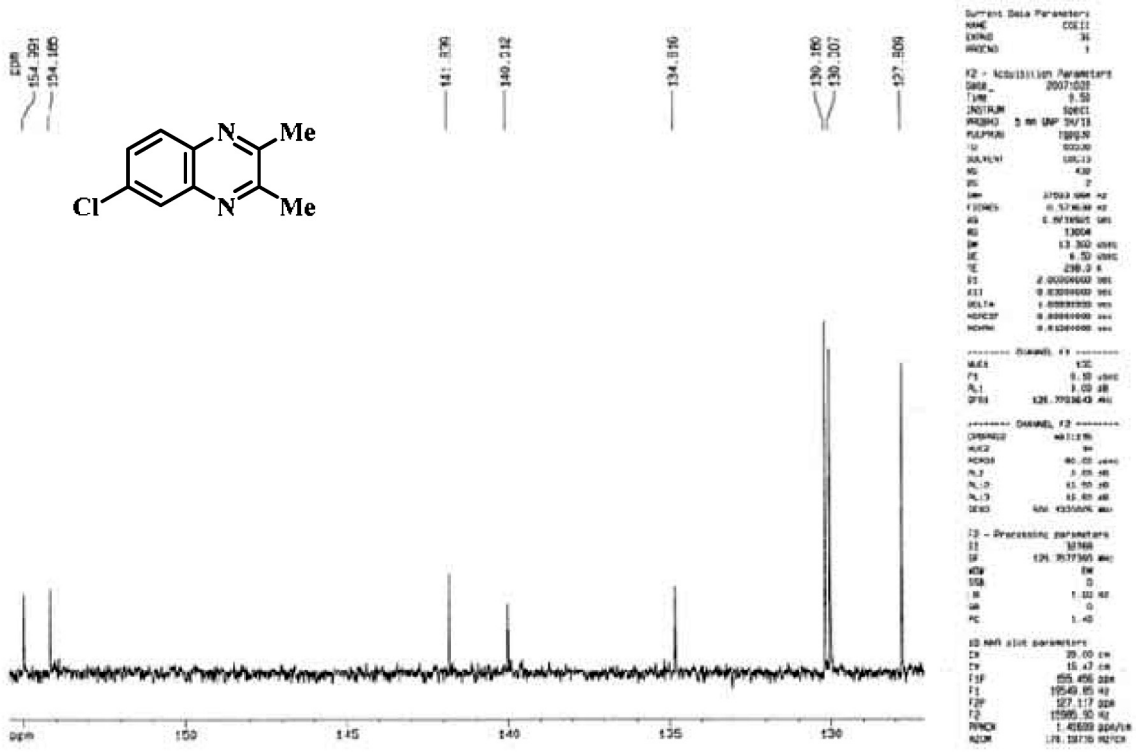

Figure S8c. ^{13}C NMR of **1l** (125 MHz, $CDCl_3$).