4.1 Introduction to Quinoxaline

Quinoxaline derivatives are of significant interest from both academic and industrial perspectives because they are noteworthy intermediates for the manufacturing of pharmaceuticals and advanced materials [1, 2]. A number of nitrogen-containing heterocycles show antimicrobial activity and have been synthesized for medical use. Among various classes of heterocyclic units, quinoxaline ring has frequently been used as a component of various antibiotic molecules, such as levomycin and hinomycin, which inhibit the growth of Gram-positive bacteria and are active against various transplantable tumors [3, 4]. Quinoxalines are very important compounds due to their wide spectrum of biological activities such as anticancer [5], antibacterial [6], and activity as kinase inhibitors [7]. They are well known for their application in rigid subunits in macrocyclic receptor [8] electroluminescent materials [9], organic semiconductors [10] and DNA cleaving agents [11].

4.2 Recent Literature Survey

Soleymani et al. [12] proposed mechanism for the formation of quinoxalines from 1,2-diamine and 1, 2-dicarbonyl compounds by using Lewis acid as the catalyst as shown in Scheme 4.1. Amino group because of non-bonding electron pair on nitrogen atom makes nucleophilic attack on to carbonyl carbon. This process is repeated twice until the removal of two water molecules to yield quinoxalines.
Considering the significant applications in the fields of medicinal, industrial and synthetic organic chemistry, there has been tremendous interest in developing efficient methods for the synthesis of quinoxalines. Improved methods have been reported by using different catalyst such as Pd \((\text{OAc})_2\) \[13\], MnO\(_2\) \[14\], CAN \[15\], manganese octahedral molecular sieves \[16\], task-specific ionic liquid \[17\] and bismuth (III) \[18\]. Although great success has been obtained in some efforts, many of these methodologies suffer one or more drawbacks such as drastic reaction conditions, low yields, and tedious work-up procedures, using toxic metal salts as catalysts, long reaction time and relatively expensive reagents. A number of synthetic strategies have been developed for the preparation of substituted quinoxalines \[8, 15, 19-25\]. The most common method involves the condensation of an aryl-1, 2-diamine with a 1, 2-dicarbonyl compound in refluxing ethanol or acetic acid for 2–12 h, and this typically gives yields of 34–70%. Hence, the search for the better method, especially the readily available and green catalysts, is still being demanded and actively pursued.

Krishnakumar et al. \[26\] synthesized quinoxaline from \(o\)-phenylenediamine and benzil by using TiO\(_2\)-P25-SO\(_4\)\(^{-2}\) as the catalyst using ethanol as the solvent at room temperature. Ishikawa et al. \[27\] synthesized derivatives of 2, 3-bis (bromomethyl)quinoxaline with substituents at the 6- and/or 7-positions by using acidic catalyst, and evaluated their activities against bacteria and fungi. Antoniotti et al. \[23\] synthesized 2, 3-susbstituted quinoxaline derivatives from epoxides and \(o\)-phenylenediamine using Bi(0)/O\(_2\)/DMSO or Bi(III)/O\(_2\)/. The use of Bi(0)/O\(_2\)/DMSO or Bi(III)/O\(_2\)/DMSO as the catalytic system in the oxidative ring opening of epoxides have already been reported \[28, 29\]. The Bi(0)-catalyzed reaction did not take place in the absence of an additve. Heravi et al. \[30\] reported ferric perchlorate catalyzed the three component condensation reaction of \(o\)-phenylenediamine, aromatic aldehydes, and cyclohexyl isocyanide to afford the corresponding N-cyclohexyl-3-aryl-quinoxaline-2-amines. Dhakshinamoorthy et al. \[31\] developed protocol in which zinc chloride-exchanged K10-montmorillonite (clay zinc) was employed as a Lewis acid catalyst in aqueous media at room temperature for the synthesis of various quinoxalines from carbonyl compounds and \(o\)-phenylenediamine. Padmavathy et al. \[32\] synthesized quinoxalines in two
stages or as a one pot reaction, starting from ketones via their α-hydroxylimino ketone derivatives, and condensation of the latter with 1, 2- diaminobenzene under microwave irradiation. Bachhav et al. [33] synthesized quinoxaline from o-phenylenediamine and 1,2 dicarbonyl compounds employing glycerol and water the as the green solvent at 90 °C. Guirado et al. [34] developed an efficient synthetic method for previously unattainable 4-alkoxy-6,9-dichloro [1,2, 4]triazolo[4,3-a] quinoxalines by reactions between 5,8-dichloro-2,3-dicyanoquinoxaline and alcohols in the presence of triethylamine led to 3-alkoxy-5,8-dichloro-2-cyanoquinoxalines. Bhosale et al. [20] synthesized quinoxaline from o-phenylenediamine and 1, 2-dicarbonyl compounds by using molecular iodine as a catalyst in DMSO as the solvent at room temperature. Corona et al. [35] synthesized a series of 5, 7-diamino-3-phenyl-2-benzylamino, 2-phenoxy and 2-phenylthio substituted quinoxalines. These compounds were evaluated for their in vitro antitumor activity towards cell lines of nine different types of human cancers. Srinivas et al. [16] synthesized biologically important quinoxaline derivatives from various 1,2-dicarbonyls and aromatic 1,2-diamines in excellent yields using very low amount of reusable polyaniline-sulfate salt catalyst. Zhang et al. [36] Chinese synthesized quinoxaline derivatives from of 1,2-diamines and 1,2-dicarbonyl compounds by using polyethylene glycol as a catalyst. Chandrasekhar et al. [37] developed a methodology employing 5 mol % of PdCl$_2$/CuCl$_2$ in PEG/H$_2$O as a efficient recyclable catalytic system for the oxidation of internal alkynes to 2, 3- disubstituted quinoxaline derivatives.

4. 3 Objectives

1. To find out new synthetic pathway for well-known condensation reactions of 1,2- diketone and α-phenylenediamines to affords various quinoxalines by employing polymer supported sulphanilic acid (ENPFSA) as the heterogeneous catalyst under different energy source such as conventional method, ultrasound irradiation and at room temperature.

2. To optimize the conditions under conventional method and ultrasound irradiation to get maximum yield in shorter duration.

3. To check the substrate scope of the novel protocol for synthesizing a good library of quinoxaline derivatives.
4. To characterize all the synthesized compounds by $^1$H NMR, $^{13}$C NMR, APT, IR, MASS spectroscopic techniques.

4.4 Result and Discussion

4.4.1 Scheme

The synthesis of 3 (Scheme 4.2) was carried out by one pot condensation of $\alpha$-phenylenediamines 1 with 1, 2 diarylketone 2 by using 5% w/w ENPFSA with respect to $\alpha$-phenylenediamines employing ethanol as the solvent by using two different energy source such as conventional and ultrasound irradiation and also at room temperature.

4.4.2 Optimization

The cyclocondensation reaction between $\alpha$-phenylenediamine (0.0105 mole) and benzil (0.01 mole) in ethanol (10 mL) under reflux to afford quinoxaline 4a (Scheme 4.2) was chosen as the model reaction for optimization.

The amount of ENPFSA was used in the ratio of % w/w with respect to $\alpha$-phenylenediamine. The optimization was carried out with respect to the amount of catalyst and duration of reaction leading to the maximum yield. The progress of the reaction was continuously monitored by thin layer chromatography (TLC) using aluminum sheets precoated with silica gel 60 F$_{254}$ (Merck) under ethylacetate: n-hexane in the ratio 50:50. The characteristic data are shown in Table 4.1.

A variety of different catalyst and ENPFSA were employed for the synthesis of quinoxaline 4a (Table 4.1, entries 1–13). The reaction was studied at reflux temperature as well as at room temperature. Increase in the reaction temperature to reflux had only marginal effect on % yield (Table 4.1). Reaction was also optimized by varying amount of ENPFSA (Table 4.1, entries 8–13). It was observed that 5% w/w amount of catalyst on the basis of $\alpha$-phenylenediamine is suitable to complete the reaction in moderate time with high yield. Higher amount of the catalyst did not increase the yield noticeably.
Model reaction was carried out by using different catalysts such as HCl, CH₃COOH, H₂SO₄, ZnCl₂, CoCl₂, NiCl₂ and PEG-600. It was found that by using HCl, CH₃COOH and H₂SO₄ as the catalysts, reaction was completed in 85 minutes with 80% yield under reflux and in 100 minutes with 75% yield at room temperature (Table 4.1, entries 1-3). By using ZnCl₂, CoCl₂, NiCl₂ as the catalysts, reaction got completed in 90 minutes with 80% yield under reflux and 110 minutes with 75% yield at room temperature (Table 1, entry 4-6). Thus the reaction was completed in shorter time with high yield by using acid catalysts as compared to metal chloride catalysts. Using PEG-600 as the catalyst, reaction was completed in 80 minutes with 85% yield under reflux and 85 minutes with 80% yield at room temperature (Table 4.1, entry 7). Model reaction was performed by using 5% ENPFSA as the catalyst, reaction was completed in 35 minutes with 90% yield under reflux and 40 minutes with 88% yield at room temperature (Table 4.1, entry 12).

Table 4.1 Effect of different catalyst on the condensation of benzil and o-phenylenediamine in ethanol as the solvent at room temperature and at reflux.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Catalyst</th>
<th>At room temp.</th>
<th>Reflux</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Timeᵃ (min)</td>
<td>Yieldsᵇ (%)</td>
</tr>
<tr>
<td>1</td>
<td>1 mmol % HCl</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td>2</td>
<td>1 mmol % CH₃COOH</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>1 mmol % H₂SO₄</td>
<td>110</td>
<td>80</td>
</tr>
<tr>
<td>4</td>
<td>1 mmol % ZnCl₂</td>
<td>110</td>
<td>80</td>
</tr>
<tr>
<td>5</td>
<td>1 mmol % CoCl₂</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>6</td>
<td>1 mmol % NiCl₂</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>7</td>
<td>1 mmol % PEG-600</td>
<td>45</td>
<td>70</td>
</tr>
<tr>
<td>8</td>
<td>1 % ENPFSA</td>
<td>45</td>
<td>72</td>
</tr>
<tr>
<td>9</td>
<td>2 % ENPFSA</td>
<td>45</td>
<td>75</td>
</tr>
<tr>
<td>10</td>
<td>3 % ENPFSA</td>
<td>45</td>
<td>80</td>
</tr>
<tr>
<td>11</td>
<td>4 % ENPFSA</td>
<td>50</td>
<td>85</td>
</tr>
<tr>
<td>12</td>
<td>5 % ENPFSA</td>
<td>50</td>
<td>85</td>
</tr>
<tr>
<td>13</td>
<td>6 % ENPFSA</td>
<td>50</td>
<td>85</td>
</tr>
</tbody>
</table>

ᵃ 5% w/w ENPFSA with respect to o-phenylenediamine was used.; ᵇ Reaction was monitored by TLC.; ᶜ Isolated yields.

Thus, it was found that the condensation reaction carried out in the presence 5% w/w ENPFSA at room temperature showed the highest conversion rate and this was chosen as the optimized condition to perform a series of reactions to check substrate dependency of the protocol.
Reaction was also optimized by using ultrasound irradiation. First the reaction was carried out without taking catalyst at room temperature under ultrasound irradiation (Table 4.2, entry 1), it was observed that after 80 min. reaction did not proceed. Reaction was carried out by taking 5% w/w with respect to amount of o-phenylenediamine at room temperature (28 °C) produced 90% yield in 30 min. (Table 4.2, entry 2)). Same reaction was performed under ultrasound irradiation at higher temperature at 50 °C (Table 4.2, entry 3), no significant increase in the yield was observed.

### Table 4.2 Optimization data for the synthesis of 1, 2-diphenylquinoxaline under ultrasound irradiation

<table>
<thead>
<tr>
<th>Entry</th>
<th>Catalyst</th>
<th>Reaction condition</th>
<th>Time (min)</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No ENPFSA</td>
<td>RT, ))))</td>
<td>80</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>5 % ENPFSA</td>
<td>RT, ))))</td>
<td>30</td>
<td>88 %</td>
</tr>
<tr>
<td>3</td>
<td>5 % ENPFSA</td>
<td>50 °C, ))))</td>
<td>30</td>
<td>90 %</td>
</tr>
</tbody>
</table>

*a* 5% w/w ENPFSA with respect to *o*-phenylenediamine was used.; *b* Reaction was monitored by TLC.; *c* Isolated yields.

### 4. 4. 3 Characteristics Data Showing the Synthesis of Benzimidazoles

By using these optimized conditions, various quinoxaline derivatives were synthesized in shorter time as well as in high yields. It was observed that diketone having phenyl ring as the substituents underwent the conversion smoothly in short time as compared to diketone having furyl and thienyl ring as the substituents. The diamine component carrying electron withdrawing group (Table 4.3, 4k-4o) underwent the reaction in shorter time with high yield as compared to diamines carrying electron donating group (Table 4.3, 4a-4j and 4p-4t).
### Table 4.3 The characteristic data showing the synthesis of quinoxalines \(^{a,b}\).

<table>
<thead>
<tr>
<th>Code</th>
<th>R</th>
<th>R(_1)</th>
<th>Ultrasound Irradiation at room temp.</th>
<th>Thermal Conditions at reflux temp.</th>
<th>At room temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Time(^{c}) (min)</td>
<td>Yield(^{d}) (%)</td>
<td>Time(^{c}) (min)</td>
</tr>
<tr>
<td>4a</td>
<td>H</td>
<td>C(_6)H(_5)</td>
<td>30</td>
<td>88</td>
<td>35</td>
</tr>
<tr>
<td>4b</td>
<td>H</td>
<td>p-CH(_3)C(_6)H(_4)</td>
<td>30</td>
<td>85</td>
<td>35</td>
</tr>
<tr>
<td>4c</td>
<td>H</td>
<td>Phenanthrene-9,10-dione(^{e})</td>
<td>32</td>
<td>85</td>
<td>30</td>
</tr>
<tr>
<td>4d</td>
<td>H</td>
<td>2-furyl</td>
<td>40</td>
<td>80</td>
<td>44</td>
</tr>
<tr>
<td>4e</td>
<td>H</td>
<td>2-thienyl</td>
<td>40</td>
<td>80</td>
<td>42</td>
</tr>
<tr>
<td>4f</td>
<td>CH(_3)</td>
<td>C(_6)H(_5)</td>
<td>38</td>
<td>85</td>
<td>40</td>
</tr>
<tr>
<td>4g</td>
<td>CH(_3)</td>
<td>p-CH(_3)C(_6)H(_4)</td>
<td>39</td>
<td>85</td>
<td>40</td>
</tr>
<tr>
<td>4h</td>
<td>CH(_3)</td>
<td>Phenanthrene-9,10-dione(^{e})</td>
<td>35</td>
<td>80</td>
<td>35</td>
</tr>
<tr>
<td>4i</td>
<td>CH(_3)</td>
<td>2-furyl</td>
<td>41</td>
<td>80</td>
<td>45</td>
</tr>
<tr>
<td>4j</td>
<td>CH(_3)</td>
<td>2-thienyl</td>
<td>40</td>
<td>80</td>
<td>46</td>
</tr>
<tr>
<td>4k</td>
<td>NO(_2)</td>
<td>C(_6)H(_5)</td>
<td>28</td>
<td>88</td>
<td>35</td>
</tr>
<tr>
<td>4l</td>
<td>NO(_2)</td>
<td>p-CH(_3)C(_6)H(_4)</td>
<td>30</td>
<td>82</td>
<td>30</td>
</tr>
<tr>
<td>4m</td>
<td>NO(_2)</td>
<td>Phenanthrene-9,10-dione(^{e})</td>
<td>30</td>
<td>85</td>
<td>31</td>
</tr>
<tr>
<td>4n</td>
<td>NO(_2)</td>
<td>2-furyl</td>
<td>42</td>
<td>88</td>
<td>42</td>
</tr>
<tr>
<td>4o</td>
<td>NO(_2)</td>
<td>2-thienyl</td>
<td>37</td>
<td>85</td>
<td>44</td>
</tr>
<tr>
<td>4p</td>
<td>Cl</td>
<td>C(_6)H(_5)</td>
<td>31</td>
<td>85</td>
<td>32</td>
</tr>
<tr>
<td>4q</td>
<td>Cl</td>
<td>p-CH(_3)C(_6)H(_4)</td>
<td>33</td>
<td>80</td>
<td>35</td>
</tr>
<tr>
<td>4r</td>
<td>Cl</td>
<td>Phenanthrene-9,10-dione(^{e})</td>
<td>37</td>
<td>85</td>
<td>38</td>
</tr>
<tr>
<td>4s</td>
<td>Cl</td>
<td>2-furyl</td>
<td>40</td>
<td>80</td>
<td>44</td>
</tr>
<tr>
<td>4t</td>
<td>Cl</td>
<td>2-thienyl</td>
<td>41</td>
<td>80</td>
<td>45</td>
</tr>
</tbody>
</table>

---

\(^{a}\) Solvent ethanol as a medium of reaction.;  \(^{b}\) 5% w/w amount of catalyst with respect to o-phenylenediamine.;  \(^{c}\) Reaction was monitored by TLC.;  \(^{d}\) Isolated yield.;  \(^{e}\) Name of the diketone

### 4.4.4 Mechanism

The formation of quinoxaline derivatives is outlined in the following mechanism (Scheme 4.3). 1, 2-Diketone stabilized in the interlayer of ENPFSA via interaction with H\(^{+}\) by partial polarization of carbonyl group reacts readily with o-phenylenediamine. The resultant amino-1, 2-diol undergoes dehydration to give quinoxaline as the end product.
4.5 Recyclability of Catalyst

Recyclability of the catalyst was studied by using the ENPFSA recovered from the previous batch. Reaction between benzil and \( o \)-phenylenediamine was taken as the model reaction. The reaction proceeded smoothly yielding 88–85% of product (Table 4.4) at room temperature for five successive turns. This result indicates that the activity of catalyst was not getting much affected upon recycling at least for five times.

**Table 4.4** Recyclability of catalyst

<table>
<thead>
<tr>
<th>No. of cycle</th>
<th>Reaction time (^a)</th>
<th>Yield (% (^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>88</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>88</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>86</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>86</td>
</tr>
<tr>
<td>5</td>
<td>40</td>
<td>85</td>
</tr>
</tbody>
</table>

\(^a\) Reaction was monitored by TLC.; \(^b\) Isolated yields.
4. 6 Conclusions

High yielding, one pot synthesis of quinoxaline derivatives from readily available \(\sigma\)-phenylenediamines and 1,2-diaryl ketones under ultrasound irradiation, room temperature and thermal condition has been developed. The conditions are mild, and a wide range of functional groups can be tolerated. NEPFSA as catalyst offers advantages including simplicity of operation, easy workup procedure, product obtained in high yields with excellent purity, less time consuming and the recyclability of the catalyst.

4. 7 Experimental

The reaction was performed in D compact ultrasonic cleaner with a frequency of 30 kHz and power 230 W. Melting points were determined using \(\mu\)ThermoCal\(_{10}\) (Analab scientific Pvt. Ltd.) melting point apparatus and are uncorrected. TLC was carried out using aluminum sheets precoated with silica gel 60 F\(_{254}\).

4. 7. 1 Chemicals and Reagents

All chemicals used were of laboratory reagent grade and used without further purification. \(\sigma\)-phenylenediamines, was obtained from Samir Tech Chem. Pvt. Ltd., Vadodara, India. Various 1, 2- diketone were used as received from Merck, Mumbai, India. All the solvents were supplied by Sisco Chem. Pvt. Ltd., Mumbai, India.

4. 7. 2 General Procedure for Synthesis of Quinoxalines

To a mixture of an \(\sigma\)-phenylenediamine (1 mmol) and benzil (1 mmol) in ethanol (5mL), 5\% w/w ENPFSA with respect to benzil was added and the mixture was stirred at room temperature. The progress of the reaction was monitored by TLC. After completion of the reaction, ethyl acetate was added to the solidified mixture and the insoluble catalyst was separated by filtration. The filtrate was dried over anhydrous Na\(_2\)SO\(_4\). The solvent was evaporated with care and the pure product was obtained. The product obtained had been characterized by FT-IR, \(^1\)HNMR, \(^{13}\)CNMR and LC-MS analysis. A variety of substituted \(\sigma\)-phenylenediamines were condensed with benzil. The recovered catalyst was washed with ethanol, chloroform, diethyl ether and subsequently
dried at 80 °C to recycle in the subsequent model reaction. Compounds 4b-t were synthesized by taking properly substituted 1, 2-dicarbonyl component in the reaction mixture.

4.8 Characterization

Melting points were determined using µThermoCal10 (Analab scientific Pvt. Ltd.) melting point apparatus and are uncorrected. $^1$H NMR and $^{13}$C NMR spectra were recorded on a Bruker Avance 400 spectrometer operating at 400 MHz for $^1$H NMR, and 100 MHz for $^{13}$C NMR, as solutions in DMSO-$d_6$. Chemical shifts (δ) are in ppm and referenced to the residual protic solvent. FT-IR spectra were recorded on Shimadzu FT-IR 8401 spectrometer using KBr disc, and are expressed in wavenumbers (cm$^{-1}$). The mass spectra (ESI-MS) were recorded on Shimadzu LCMS-2010 spectrometer.

For 4n & 4q compounds of the series, the representative spectra are included at the end of the section for perusal. $^1$H NMR spectrum for 4n & 4q are given in Figure 4.1 & Figure 4.6 respectively, $^{13}$C NMR spectrum are given Figure 4.2 & Figure 4.7. APT spectrum of 4n & 4q are given in Figure 4.3 & Figure 4.8 respectively. The infrared spectrum is shown in Figure 4.4 for 4n and Figure 4.9 for 4q. The mass spectrum obtained for the same compounds are given in Figure 4.5 & Figure 4.10 respectively. The molecular structures and characterization of all the synthesized quinoxalines are given below.
4a. 2, 3-diphenylquinoxaline

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular Formula</td>
<td>C_{20}H_{14}N_{2}</td>
</tr>
<tr>
<td>Molecular Weight (g·mol⁻¹)</td>
<td>282.12</td>
</tr>
<tr>
<td>Melting Point (°C)</td>
<td>126</td>
</tr>
</tbody>
</table>

\(^1\)H NMR (400 MHz, DMSO, \(\delta \) ppm): 7.85-7.60 (m, 4H, Ar-H), 7.60 - 7.45 (m, 10H, Ar-H)

\(^{13}\)C NMR (100 MHz, DMSO, \(\delta \) ppm): 155.2, 142.4, 138.4, 129.8, 129.6, 129.4, 127.8

DEPT-135: Up peaks: 155.2, 142.4, 138.4
Down peaks: 129.8, 129.6, 129.4, 127.8

IR (KBr): 1608, 1467, 1335, 1242, 1185, 1065, 980, 818, 726, 612 cm⁻¹

LC-MS: 322.1

% C, H, N Analysis: Calculated: C, 85.05; H, 5.00; N, 9.9
Observed: C, 85.10; H, 5.06; N, 9.98

4b. 2,3-dip-tolylquinoxaline

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular Formula</td>
<td>C_{22}H_{18}N_{2}</td>
</tr>
<tr>
<td>Molecular Weight (g·mol⁻¹)</td>
<td>310.15</td>
</tr>
<tr>
<td>Melting Point (°C)</td>
<td>147</td>
</tr>
</tbody>
</table>

\(^1\)H NMR (400 MHz, DMSO, \(\delta \) ppm): 7.85-7.60 (m, 4H, Ar-H), 7.60 - 7.20 (m, 8H, Ar-H), 2.35 (s, 6H)

\(^{13}\)C NMR (100 MHz, DMSO, \(\delta \) ppm): 155.2, 142.4, 135.4, 131.4, 129.9, 129.8, 129.6, 21.4

DEPT-135: Up peaks: 155.2, 142.4, 135.4, 131.4
Down peaks: 129.9, 129.8, 129.6, 21.4

IR (KBr): 1608, 1464, 1335, 1244, 1180, 1069, 980, 819, 725, 603 cm⁻¹

LC-MS: 311.2

% C, H, N Analysis: Calculated: C, 85.13; H, 5.85; N, 9.03
Observed: C, 85.16; H, 5.91; N, 9.08
### 4c. dibenzo[a,c]phenazine

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular Formula</td>
<td>C_{20}H_{12}N_{2}</td>
</tr>
<tr>
<td>Molecular Weight (g·mol⁻¹)</td>
<td>280.32</td>
</tr>
<tr>
<td>Melting Point (°C)</td>
<td>225</td>
</tr>
</tbody>
</table>

\[ ^1H \text{ NMR (400 MHz, DMSO, } \delta \text{ ppm): 9.10-7.88 (m, 8H, Ar-H), 7.85-7.60 (m, 4H, Ar-H) } \]

\[ ^13C \text{ NMR (100 MHz, DMSO, } \delta \text{ ppm): 142.4, 129.8, 129.2, 127.6, 126.8, 125.6, 122.6 } \]

DEPT-135: Up peaks: 142.4, 129.8, 127.6  
Down peaks: 129.2, 126.8, 125.6, 122.6

IR (KBr): 1608, 1467, 1336, 1242, 1181, 1065, 980, 817, 725, 605 cm⁻¹

LC-MS: 281.3

% C, H, N Analysis: Calculated: C, 85.69; H, 4.31; N, 9.99  
Observed: C, 85.72; H, 4.36; N, 10.03

### 4d. 2,3-di(furan-2-yl)quinoxaline

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\[ ^1H \text{ NMR (400 MHz, DMSO, } \delta \text{ ppm): 7.85-7.60 (m, 4H, Ar-H), 7.60-6.90 (m, 6H, Ar-H) } \]

\[ ^13C \text{ NMR (100 MHz, DMSO, } \delta \text{ ppm): 157.9, 144.6, 142.6, 142.4, 129.8, 129.5, 112.4, 107.5 } \]

DEPT-135: Up peaks: 157.9, 144.6, 142.4  
Down peaks: 142.6, 129.8, 129.5, 112.4, 107.5

IR (KBr): 1606, 1467, 1332, 1240, 1180, 1065, 981, 817, 728, 609 cm⁻¹

LC-MS: 263.3

% C, H, N Analysis: Calculated: C, 73.27; H, 3.84; N, 10.68  
Observed: C, 73.32; H, 3.89; N, 10.71
4e. 2,3-di(thiophen-2-yl)quinoxaline

Molecular Formula: $\text{C}_{16}\text{H}_{10}\text{N}_{2}\text{S}_{2}$

Molecular Weight (g·mol$^{-1}$): 294.39

Melting Point ($^{\circ}$C): 140

$^1\text{H}$ NMR (400 MHz, DMSO, $\delta$ ppm): 7.85-7.60 (m, 4H, Ar-H), 7.62-6.90 (m, 6H, Ar-H)

$^{13}$C NMR (100 MHz, DMSO, $\delta$ ppm): 145.2, 139.8, 139.5, 129.4, 128.4, 128.1, 127.8

DEPT-135: Up peaks: 145.2, 139.8, 139.5

Down peaks: 129.4, 128.4, 128.1, 127.8

IR (KBr): 1600, 1467, 1335, 1248, 1188, 1065, 985, 818, 725, 602 cm$^{-1}$

LC-MS: 295.4

% C, H, N Analysis: Calculated: C, 65.28; H, 3.42; N, 9.52

Observed: C, 65.33; H, 3.49; N, 9.57

4f. 6-methyl-2,3-diphenylquinoxaline

Molecular Formula: $\text{C}_{21}\text{H}_{16}\text{N}_{2}$

Molecular Weight (g·mol$^{-1}$): 296.37

Melting Point ($^{\circ}$C): 116

$^1\text{H}$ NMR (400 MHz, DMSO, $\delta$ ppm): 8.10-7.50 (m, 3H, Ar-H), 7.50-7.40 (m, 10H, Ar-H), 2.35 (s, 3H)

$^{13}$C NMR (100 MHz, DMSO, $\delta$ ppm): 155.4, 154.2, 142.4, 140.6, 138.9, 138.6, 134.6, 129.0, 128.9, 127.6, 127.2, 21.4

DEPT-135: Up peaks: 155.4, 154.2, 142.4, 140.6, 138.9, 138.6

Down peaks: 134.6, 129.0, 128.9, 127.6, 127.2, 21.4

IR (KBr): 1608, 1467, 1339, 1242, 1180, 1065, 980, 818, 720, 606 cm$^{-1}$

LC-MS: 297.4

% C, H, N Analysis: Calculated: C, 85.11; H, 5.44; N, 9.45

Observed: C, 85.15; H, 5.48; N, 9.49
4g. 6-methyl-2,3-dip-tolylquinoxaline

Molecular Formula \( \text{C}_{23}\text{H}_{20}\text{N}_{2} \)

Molecular Weight (g·mol\(^{-1}\)) 324.42

Melting Point (°C) 137

\(^1\)H NMR (400 MHz, DMSO, \( \delta \) ppm): 8.10-7.50 (m, 3H, Ar-H), 7.52-7.28 (m, 8H, Ar-H), 2.35 (s, 9H)

\(^{13}\)C NMR (100 MHz, DMSO, \( \delta \) ppm): 155.4, 154.2, 142.2, 140.4, 138.8, 135.4, 134.6, 131.9, 129.6, 128.6, 127.8, 125.9, 21.4

DEPT-135: Up peaks: 155.4, 154.2, 142.2, 140.4, 138.8, 135.4, 134.6, 131.9

Down peaks: 129.6, 128.6, 127.8, 125.9, 21.4

IR (KBr): 1602, 1465, 1332, 1242, 1180, 1062, 970, 818, 735, 612 cm\(^{-1}\)

LC-MS: 325.4

% C, H, N Analysis: Calculated: C, 85.15; H, 6.21; N, 8.63
Observed: C, 85.19; H, 6.26; N, 8.68

4h. 11-methyldibenzo[a,c]phenazine

Molecular Formula \( \text{C}_{21}\text{H}_{14}\text{N}_{2} \)

Molecular Weight (g·mol\(^{-1}\)) 294.35

Melting Point (°C) 209

\(^1\)H NMR (400 MHz, DMSO, \( \delta \) ppm): 8.95-8.10 (m, 8H, Ar-H), 8.10-7.50 (m, 3H, Ar-H), 2.35 (s, 3H)

\(^{13}\)C NMR (100 MHz, DMSO, \( \delta \) ppm): 142.3, 140.1, 138.8, 138.9, 134.6, 129.8, 128.6, 127.9, 127.8, 127.6, 126.8, 126.4, 125.9, 122.6, 21.4

DEPT-135: Up peaks: 142.3, 140.1, 138.8, 129.8, 127.6, 126.8

Down peaks: 138.9, 134.6, 128.6, 127.9, 127.8, 126.4, 125.9, 122.6, 21.4

IR (KBr): 1604, 1462, 1332, 1240, 1179, 1061, 980, 818, 725, 610 cm\(^{-1}\)

LC-MS: 295.4

% C, H, N Analysis: Calculated: C, 85.69; H, 4.79; N, 9.52
Observed: C, 85.73; H, 4.84; N, 9.58
4i. 2,3-di(furan-2-yl)-6-methylquinoxaline

Molecular Formula \( \text{C}_{17}\text{H}_{12}\text{N}_2\text{O}_2 \)

Molecular Weight (g·mol\(^{-1}\)) 276.29

Melting Point (°C) 118

\(^1\)H NMR (400 MHz, DMSO, \( \delta \) ppm): 8.10-7.50 (m, 3H, Ar-H), 7.50-6.90 (m, 6H, Ar-H), 2.35 (s, 3H)

\(^{13}\)C NMR (100 MHz, DMSO, \( \delta \) ppm): 157.8, 144.3, 143.5, 142.8, 142.2, 140.4, 138.9, 134.8, 128.4, 127.8, 112.4, 107.2, 21.4

DEPT-135: Up peaks: 157.8, 144.3, 143.5, 142.2, 140.4, 138.9

Down peaks: 142.8, 134.8, 128.4, 127.8, 112.4, 107.2, 21.4

IR (KBr): 1610, 1462, 1337, 1242, 1184, 1065, 984, 818, 726, 603 cm\(^{-1}\)

LC-MS: 277.3

\% C, H, N Analysis: Calculated: C, 73.90; H, 4.38; N, 10.14

Observed: C, 73.96; H, 4.44; N, 10.19

4j. 6-methyl-2,3-di(thiophen-2-yl)quinoxaline

Molecular Formula \( \text{C}_{17}\text{H}_{12}\text{N}_2\text{S}_2 \)

Molecular Weight (g·mol\(^{-1}\)) 308.42

Melting Point (°C) 110

\(^1\)H NMR (400 MHz, DMSO, \( \delta \) ppm): 8.10-7.50 (m, 3H, Ar-H), 7.50-7.10 (m, 6H, Ar-H), 2.35 (s, 3H)

\(^{13}\)C NMR (100 MHz, DMSO, \( \delta \) ppm): 144.7, 144.3, 142.2, 140.4, 140.8, 138.9, 134.6, 128.8, 128.6, 128.2, 128.1, 127.4, 21.4

DEPT-135: Up peaks: 144.7, 144.3, 142.2, 140.4, 140.8, 138.9

Down peaks: 134.6, 128.8, 128.6, 128.2, 128.1, 127.4, 21.4

IR (KBr): 1609, 1467, 1338, 1242, 1180, 1055, 981, 817, 722, 605 cm\(^{-1}\)

LC-MS: 309.4

\% C, H, N Analysis: Calculated: C, 66.20; H, 3.92; N, 9.08

Observed: C, 66.28; H, 3.98; N, 9.13
4k. 6-nitro-2,3-diphenylquinoxaline

**Molecular Formula** \( \text{C}_{20}\text{H}_{13}\text{N}_3\text{O}_2 \)

**Molecular Weight (g·mol\(^{-1}\))** 327.34

**Melting Point (°C)** 192

\(^1\text{H NMR (400 MHz, DMSO, } \delta \text{ ppm):}\) 9.10-7.90 (m, 3H, Ar-H), 7.60-7.35 (m, 10H, Ar-H)

\(^{13}\text{C NMR (100 MHz, DMSO, } \delta \text{ ppm):}\) 159.2, 157.4, 144.8, 141.4, 138.4, 129.4, 128.9, 128.4, 127.6, 123.6, 122.8

**DEPT-135:**
- **Up peaks:** 159.2, 157.4, 144.8, 141.4, 138.4
- **Down peaks:** 129.4, 128.9, 128.4, 127.6, 123.6, 122.8

**IR (KBr):** 1608, 1467, 1338, 1244, 1180, 1065, 980, 816, 729, 612 cm\(^{-1}\)

**LC-MS:** 328.4

% C, H, N Analysis:
- **Calculated:** C, 73.38; H, 4.00; N, 12.84
- **Observed:** C, 73.38; H, 4.00; N, 12.84

4l. 6-nitro-2,3-dip-tolylquinoxaline

**Molecular Formula** \( \text{C}_{22}\text{H}_{17}\text{N}_3\text{O}_2 \)

**Molecular Weight (g·mol\(^{-1}\))** 355.39

**Melting Point (°C)** 168

\(^1\text{H NMR (400 MHz, DMSO, } \delta \text{ ppm):}\) 9.10-7.90 (m, 3H, Ar-H), 7.70-7.25 (m, 8H, Ar-H), 2.35 (s, 6H)

\(^{13}\text{C NMR (100 MHz, DMSO, } \delta \text{ ppm):}\) 159.2, 157.4, 144.8, 141.3, 135.4, 131.9, 129.6, 128.4, 125.8, 123.6, 21.4

**DEPT-135:**
- **Up peaks:** 159.2, 157.4, 144.8, 141.3, 135.4, 131.9
- **Down peaks:** 129.6, 128.4, 125.8, 123.6, 21.4

**IR (KBr):** 1610, 1467, 1338, 1244, 1185, 1065, 987, 821, 730, 607 cm\(^{-1}\)

**LC-MS:** 356.4

% C, H, N Analysis:
- **Calculated:** C, 74.35; H, 4.82; N, 11.82
- **Observed:** C, 74.38; H, 4.86; N, 11.88
4m. 11-nitro dibenzo[a,c]phenazine

Molecular Formula: C_{20}H_{11}N_{3}O_{2}

Molecular Weight (g· mol\(^{-1}\)): 325.32

Melting Point (°C): 245

\(^1\)H NMR (400 MHz, DMSO, \(\delta\) ppm): 9.10-7.90 (m, 3H, Ar-H), 9.0-7.80 (m, 8H, Ar-H)

\(^{13}\)C NMR (100 MHz, DMSO, \(\delta\) ppm): 144.8, 141.4, 129.8, 128.4, 127.8, 126.8, 125.8, 123.6, 122.8, 122.6

DEPT-135: Up peaks: 144.8, 141.4, 129.8, 127.8, 126.8
Down peaks: 128.4, 125.8, 123.6, 122.8, 122.6

IR (KBr): 1604, 1464, 1336, 1244, 1184, 1070, 980, 819, 730, 603 cm\(^{-1}\)

LC-MS: 326.3

% C, H, N Analysis: Calculated: C, 73.84; H, 3.41; N, 12.92
Observed: C, 73.88; H, 3.45; N, 12.97

4n. 2,3-di(furan-2-yl)-6-nitroquinoxaline

Molecular Formula: C_{16}H_{9}N_{3}O_{4}

Molecular Weight (g· mol\(^{-1}\)): 307.26

Melting Point (°C): 165

\(^1\)H NMR (400 MHz, DMSO, \(\delta\) ppm): 8.77-8.20 (m, 3H, Ar-H), 7.98-6.75 (m, 6H, Ar-H)

\(^{13}\)C NMR (100 MHz, DMSO, \(\delta\) ppm): 150.1, 150.0, 148.0, 146.0, 146.2, 146.7, 144.5, 144.0, 142.8, 138.9, 130.8, 124.9, 124.2, 113.0, 112.8

DEPT-135: Up peaks: 150.1, 150.0, 148.0, 146.7, 142.8
Down peaks: 146.2, 146.0, 144.5, 144.0, 138.9, 130.8, 130.7, 124.9, 124.2, 113.0, 112.8

IR (KBr): 1566, 1520, 1474, 1342, 1011, 910, 887 cm\(^{-1}\)

LC-MS: 308.1

% C, H, N Analysis: Calculated: C, 62.54; H, 2.95; N, 13.68
Observed: C, 62.63; H, 2.35; N, 20.94
4o. 6-nitro-2,3-di(thiophen-2-yl)quinoxaline

Molecular Formula  \( C_{16}H_{9}N_{3}S_{2}O_{2} \)

Molecular Weight (g·mol\(^{-1}\))  339.39

Melting Point (°C)  220

\(^1\)H NMR (400 MHz, DMSO, \( \delta \) ppm): 9.90-7.90 (m, 3H, Ar-H), 7.70-7.50 (m, 6H, Ar-H)

\(^{13}\)C NMR (100 MHz, DMSO, \( \delta \) ppm): 149.2, 147.6, 144.8, 141.4, 140.1, 128.5, 128.4, 128.0, 127.8, 123.6, 122.8

DEPT-135: Up peaks: 149.2, 147.6, 144.8, 141.4, 140.1

Down peaks: 128.5, 128.4, 128.0, 127.8, 123.6, 122.8

IR (KBr): 1608, 1462, 1335, 1242, 1183, 1064, 980, 819, 726, 600 cm\(^{-1}\)

LC-MS: 340.4

\% C, H, N Analysis: Calculated: C, 56.62; H, 2.67; N, 12.38

Observed: C, 56.68; H, 2.71; N, 12.44

4p. 6-chloro-2,3-diphenylquinoxaline

Molecular Formula  \( C_{20}H_{13}ClN_{2} \)

Molecular Weight (g·mol\(^{-1}\))  316.78

Melting Point (°C)  115

\(^1\)H NMR (400 MHz, DMSO, \( \delta \) ppm): 7.15-7.11 (m, 3H, Ar-H), 7.50-7.40 (m, 10H, Ar-H)

\(^{13}\)C NMR (100 MHz, DMSO, \( \delta \) ppm): 156.4, 155.4, 144.2, 142.4, 140.4, 138.4, 131.8, 130.9, 129.1, 128.9, 128.4, 127.6

DEPT-135: Up peaks: 156.4, 155.4, 144.2, 142.4, 140.4, 138.4

Down peaks: 131.8, 130.9, 129.1, 128.9, 128.4, 127.6

IR (KBr): 1568, 1522, 1476, 1348, 1011, 910, 888, 625 cm\(^{-1}\)

LC-MS: 317.8

\% C, H, N Analysis: Calculated: C, 75.83; H, 4.14; N, 11.19

Observed: C, 75.86; H, 4.19; N, 11.24
### 4q. 6-chloro-2, 3-dip-tolylquinoxaline

**Molecular Formula**  \( \text{C}_{22}\text{H}_{17}\text{ClN}_{2} \)

**Molecular Weight (g·mol\(^{-1}\))**  344.11

**Melting Point (°C)**  170

**\(^1\)H NMR (400 MHz, DMSO, \( \delta \) ppm):** 8.19-7.85 (m, 3H, Ar-H), 7.37 (m, 4H, Ar-H), 7.17 (m, 4H, Ar-H), 2.30 (s, 6H);

**\(^{13}\)C NMR (100 MHz, DMSO, \( \delta \) ppm):** 154.4, 153.8, 141.1, 139.5, 139.1, 139.0, 136.1, 136.1, 134.8, 131.2, 131.1, 130.1, 129.6, 129.4, 129.2, 129.1, 128.9, 127.9, 127.8

**DEPT-135:** Up peaks: 154.4, 153.8, 141.1, 139.5, 139.1, 139.0, 136.1, 136.1, 134.8

**Down peaks:** 131.2, 131.1, 130.1, 129.6, 129.4, 129.2, 129.1, 128.9, 127.9, 127.8

**IR (KBr):** 1605, 1466, 1335, 1242, 1180, 1065, 980, 818, 725, 602 cm\(^{-1}\)

**LC-MS:** 345.2

**% C, H, N Analysis:** Calculated: C, 76.63; H, 4.97; N, 8.12

Observed: C, 76.93; H, 5.31; N, 8.25

---

### 4r. 11-chlorodibenzo[a,c]phenazine

**Molecular Formula**  \( \text{C}_{20}\text{H}_{11}\text{ClN}_{2} \)

**Molecular Weight (g·mol\(^{-1}\))**  314.77

**Melting Point (°C)**  225

**\(^1\)H NMR (400 MHz, DMSO, \( \delta \) ppm):** 7.15-7.11 (m, 3H, Ar-H), 8.20-7.80 (m, 8H, Ar-H)

**\(^{13}\)C NMR (100 MHz, DMSO, \( \delta \) ppm):** 142.4, 144.2, 140.4, 131.8, 130.7, 129.8, 128.1, 127.7, 126.8, 126.6, 125.9, 122.5

**DEPT-135:** Up peaks: 142.4, 144.2, 140.4, 129.8, 127.7, 126.8, 126.6, 122.5

**Down peaks:** 131.8, 130.7, 128.1, 125.9

**IR (KBr):** 1569, 1520, 1479, 1346, 1015, 910, 889, 610 cm\(^{-1}\)

**LC-MS:** 315.8

**% C, H, N Analysis:** Calculated: C, 76.31; H, 3.52; N, 8.90

Observed: C, 76.37; H, 3.58; N, 8.95
### 4s. 6-chloro-2,3-di(furan-2-yl)quinoxaline

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<td>Molecular Weight (g·mol⁻¹)</td>
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<td>Melting Point (°C)</td>
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**¹H NMR (400 MHz, DMSO, δ ppm):** 7.15-7.11 (m, 3H, Ar-H), 7.60-6.90 (m, 6H, Ar-H)

**¹³C NMR (100 MHz, DMSO, δ ppm):** 167.2, 157.8, 145.6, 144.7, 142.7, 142.5, 141.6, 140.4, 131.9, 130.9, 128.4, 112.3

**DEPT-135:**
- **Up peaks:** 157.8, 145.6, 144.7, 142.5, 141.6, 140.4
- **Down peaks:** 167.2, 142.7, 131.9, 130.9, 128.4, 112.3

**IR (KBr):** 1568, 1522, 1474, 1345, 1019, 910, 805, 602 cm⁻¹

**LC-MS:** 297.7

**% C, H, N Analysis:**
- Calculated: C, 64.77; H, 3.06; N, 9.44
- Observed: C, 64.79; H, 3.10; N, 9.49

---

### 4t. 6-chloro-2,3-di(thiophen-2-yl)quinoxaline

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**¹H NMR (400 MHz, DMSO, δ ppm):** 7.15-7.11 (m, 3H, Ar-H), 7.50-7.70 (m, 6H, Ar-H)

**¹³C NMR (100 MHz, DMSO, δ ppm):** 146.7, 145.4, 142.5, 141.5, 140.6, 139.8, 130.4, 131.8, 128.4, 128.3, 128.2, 127.4

**DEPT-135:**
- **Up peaks:** 146.7, 145.4, 142.5, 141.5, 140.6, 139.8, 130.4
- **Down peaks:** 131.8, 128.4, 128.3, 128.2, 127.4

**IR (KBr):** 1567, 1522, 1476, 1348, 1019, 910, 887, 610 cm⁻¹

**LC-MS:** 329.8

**% C, H, N Analysis:**
- Calculated: C, 58.44; H, 2.76; N, 8.52
- Observed: C, 58.48; H, 2.78; N, 8.58
Synthesis & characterization of quinoxalines

Figure 4.1 $^1$H NMR spectrum of 4n 2, 3-di(furan-2-yl)-6-nitroquinoxaline

Figure 4.2 $^{13}$C NMR spectrum of 4n 2, 3-di(furan-2-yl)-6-nitroquinoxaline
Figure 4.3 $^{13}$C NMR spectrum of $4n$ 2, 3-di(furan-2-yl)-6-nitroquinoxaline

Figure 4.4 IR spectrum of $4n$ 2, 3-di(furan-2-yl)-6-nitroquinoxaline
Figure 4.5 Mass spectrum of \(4n\) 2, 3-di(furan-2-yl)-6-nitroquinoxaline

Figure 4.6 \(^1\)H NMR spectrum of \(4q\) 6-chloro-2, 3-di\(p\)-tolylquinoxaline
Synthesis & characterization of quinoxalines

Figure 4.7 $^{13}$C NMR spectrum of 4q 6-chloro-2, 3-dip-tolylquinoxaline

Figure 4.8 APT spectrum of 4q 6-chloro-2, 3-dip-tolylquinoxaline
Figure 4.9 IR spectrum of 4q 6-chloro-2, 3-di-p-tolylquinoxaline

Figure 4.10 Mass spectrum of 4q 6-chloro-2, 3-di-p-tolylquinoxaline
References


