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Catalytic Synthesis of 2,3-Diphenylquinoxalines at Room Temperature Using Silica Supported Preyssler Heteropolyacid Catalysts, $H_{14}[NaP_5W_{30}O_{110}]/SiO_2$

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Abstract: The reaction of Preyssler heteropolyacid, which was used as a catalyst for the room temperature synthesis of quinoxaline derivatives from 1,2-diamino compounds and 1,2-dicarbonyl compounds. The catalyst could be recycled and reused several times without any loss of efficiency.

Keywords: Quinoxalines, 1,2-Diamino Compounds, 1,2-Dicarbonyl Compounds, Preyssler, Catalyst

1. Introduction

In the last decades, heteropolyacids (HPAs) and related polyoxometalate compounds have attracted much attention as economically and environmentally friendly catalysts [1-8]. HPAs have very strong Brønsted acidity, approaching the superacid range and they are also efficient oxidants. HPAs are very soluble in polar solvents such as water, alcohols, ketones, *etc.* Therefore, HPAs are employed in homogeneous systems as acid and oxidation catalysts and, particularly, they show higher catalytic activity than mineral acids [2,6,9]. On the other hand, HPAs are nontoxic and mildly to non-corrosive, so they are generally recognized as clean and safe catalysts. Although homogeneous catalytic processes are efficient for a wide variety of reactions, they have some disadvantages. The difficulty in separation of catalyst from the product has led to economical and environmental problems, which is also inconvenient in continuous production. To solve these problems, scientists have mainly explored three different ways to prepare heterogeneous HPA catalysts. A quinoxaline moiety serves as the nucleus for the synthesis of several biologically active compounds including antitumor [10], antimycobacterial [11] and antidepressant [12] drugs. Some antibiotics, such as levomycin, actinoleutin and echinomycin also contain a quinoxaline scaffold and these are known to inhibit the growth of Gram positive bacteria [13] and are active against various transplantable tumors [14]. As a part of our ongoing research leading to the synthesis of novel anticancer drugs [15-21]. These compounds constitute an important class of benzoheterocycles displaying a broad spectrum of biological activities, which have made them privileged structures in pharmacologically active compounds [22,11]. They have also been used as building blocks in the synthesis of organic semiconductors [23], rigid subunits in macrocyclic receptors or for molecular recognition [24], and as chemically controllable switches [25]. In general, these compounds can be produced via the condensation in organic solvents of 1,2-diamines with 1,2-dicarbonyl compounds under refluxing conditions with 34-85% yields for 2-12 h [26]. However, most of the traditional processes suffer from a variety of disadvantages such as pollution, high cost, poor chemical yields, requirements for long reaction times, and tedious work-up procedures, which limit their use as environmentally benign processes. Some progress on the synthesis of quinoxaline derivatives has been reported in the literature, for example: the Bi-catalyzed oxidative coupling reaction [27], a tandem oxidation process using $Pd(OAc)_2$ or

$RuCl_2$-$(PPh_3)_3$-TEMPO [28], and MnO_2 [29], heteroannulation of nitroketene *N,S*-arylaminoacetals with $POCl_3$ [30], cyclization of α-arylimino oximes compounds under refluxing condition in acetic anhydride [31]. Also, there are recent reports on the condensation of *o*-phenylene diamines and 1,2-dicarbonyl compounds in the presence of PbO [32], Zn[(L)-proline] in HOAc [33], copper chloride [34], montmorillonite K-10 [35], ([Hbim]BF_4) [36], metal hydrogen sulfates [37], and oxalic acid [38]. Although diverse methods for the synthesis of substituted quinoxalines are described in the literature [39,40], the most common method for their preparation is a condensation reaction between a 1,2-diamine and 1,2-dicarbonyl compound. Clearly, all while these methods have extended the scope for the synthesis of this type of heterocycles, they have limitations in some of the following areas: low yield, long reaction time, difficult product isolation procedure and use of toxic metal catalysts as well as hazardous solvents.

2. Experimental

2.1. Materials and Instruments

All chemicals were obtained from Merck and used as received. ^{1}H NMR spectra were recorded on a FT NMR Bruker 400 MHz spectrometer at 298 K. Melting points were recorded on an Electrothermal type 9100 melting point apparatus andwere uncorrected. Chemical shifts were reported in ppm (δ-scale) relative to internal standard TMS (0.00 ppm); the solvent was used as a reference. IR spectra were obtained with a Buck 500 scientific spectrometer (KBr pellets). The products were identified by comparison of their mp., IR and NMR spectra with those of authentic samples. Column chromatography was performed using EM silica gel 60 (300-400 mesh).

2.2. Preparation of Preyssler Catalyst

$H_{14}[NaP_5W_{30}O_{110}]$, ($H_{14}$-$P_5$) was prepared by passage of a solution of the potassium salt in water through a column (50 cm x 1 cm) of Dowex 50Wx8 in the H^+ form and evaporation of the elute to dryness under vacuum. Silica-supported Preyssler heteropolyacid, $H_{14}[NaP_5W_{30}O_{110}]/SiO_2$ catalysts were prepared by impregnating Aerosil 300 silica with a methanol solution of $H_{14}[NaP_5W_{30}O_{110}]/SiO_2$ [41,42].

2.3. General Procedure for the Preparation of Quinoxalines (3)

To a stirred solution of 1, 2-diketone (1) (1 mmol), dicarbonyl compound (2) (1 mmol) in ethanol (2 mL) was added silica-supported Preyssler heteropolyacid catalyst, $H_{14}[NaP_5W_{30}O_{110}]/SiO_2$ (0.05 g) with different laodings, solvent (5 mL) and stirred at room temperature. The progress of the reaction was monitored by TLC. After completion of the reaction, the mixture was filtered, and the remaining was washed with warm ethanol in order to separate catalyst. Then water (20 mL) was added to the filtrate, and was allowed to stand at room temperature for 1 h. During this time, crystals of the pure product were formed which were collected by filtration and dried and to give the product 3. For further purification if needed, the products recrystallized from hot ethanol.

The spectral and analytical data of all compounds are given below.

2,3-Bis(4-chlorophenyl)quinoxaline (1): M. P.: 195-196°C (lit. [34] 195-196°C); IR (KBr) ν_{max}/cm^{-1}: 3055, 1540, 1345, 768, 727 ; ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.38 (dt, 4H, *J* = 8.5 Hz, *J* = 2.0 Hz), 7.50 (dt, 4H, *J* = 8.5 Hz, *J* = 2.0 Hz), 7.82 (d, 2H, *J* = 6.3 Hz, *J* = 3.4 Hz), 8.20 (d, 2H, *J*= 6.3 Hz, *J*= 3.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 129.14, 129.63, 130.79, 131.60, 135.76, 137.67, 141.65, 152.34. Anal. Calcd for $C_{20}H_{12}Cl_2N_2$: C 68.39, H 3.44, N 7.98%. Found: C 68.31, H 3.40, N 7.94%; MS (*m/z*): 350.0 (M+). HRMS (EI) Calcd. for $C_{20}H_{12}Cl_2N_2$ $[M]^+$, 350.001, Found 350.009.

2,3-Bis(4-methoxyphenyl)quinoxaline (2): mp 148-150°C (lit. [39] 148-150°C); IR (KBr) ν_{max}/cm^{-1}: 3001, 2930, 1605, 1510, 1344, 1056, 878; ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 3.85 (s, 6H), 6.86 (d, 4H, *J* = 8.6 Hz), 7.49 (d, 4H, *J* = 8.6 Hz), 7.69 (m, 2H), 8.20 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 160.40, 155.31, 142.29, 128.51, 128.81, 129.30, 127.11, 114.67, 55.76. Anal. Calcd for $C_{22}H_{18}N_2O_2$: C 77.17, H 5.30, N 8.18%. Found: C 77.12, H 5.24, N 7.08%; HRMS (EI) Calcd. for $C_{22}H_{18}N_2O_2$ $[M]^+$, 342.1001, Found 350.1008.

2,3-Bis(4-methoxyphenyl)-6-methylquinoxaline (3): M. P.: 129-131°C (lit. [36] 129-131°C); IR (KBr) ν_{max}/cm^{-1}: 3065, 1660, 1590, 1212, 874, 719, 640; ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 1.57 (s, 3H), 3.86 (s, 6H), 6.65 (d, 4H, *J* = 8.6 Hz), 7.06 (d, 4H, *J* = 8.6 Hz), 7.60 (d, 1H, *J* = 8.5 Hz), 7.90 (s, 1H), 8.09 (d, 1H, *J* = 8.5 Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 22.5, 56.6, 115.2, 128.7, 135.5, 139.4, 141.9, 143.4, 154.8, 161.0. Anal. Calcd for $C_{23}H_{20}N_2O_2$: C 77.51, H 5.66, N 7.86%. Found: C 77.42, H 5.61, N 7.83%; HRMS (EI) Calcd. for $C_{23}H_{20}N_2O_2$ $[M]^+$, 356.2001, Found 350.1009.

2,3-Bis(4-bromophenyl)quinoxaline (4): M. P.: 192-194°C (lit. [37] 194-195°C); IR (KBr) ν_{max}/cm^{-1}: 3055, 1540, 1346, 768, 728; ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.40 (dt, 4H, *J* = 8.5 Hz, *J* = 2.0 Hz), 7.52 (dt, 4H, *J* = 8.5 Hz, *J* = 2.0 Hz), 7.78 (d, 2H, *J* = 6.5 Hz, *J* = 3.5 Hz), 8.15 (d, 2H, *J* = 6.5 Hz, *J* = 3.5 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 124.15, 129.65, 130.83, 131.87, 132.12, 138.14, 141.67, 152.34. Anal. Calcd for $C_{20}H_{12}N_2Br_2$: C 54.58, H 2.75, N 6.36%. Found: C 54.52, H 2.71, N 6.33%; HRMS (EI) Calcd. for $C_{20}H_{12}N_2Br_2$ $[M]^+$, 437.9000, Found 437.9007.

2,3-Diphenylquinoxaline (5): M. P.: 126-127°C (lit. [34] 128-129°C); IR (KBr) ν_{max}/cm^{-1}: 3055, 1540, 1345, 769, 729; ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.40 (m, 6H), 7.57 (m, 4H), 7.80 (m, 2H), 8.24 (d, 2H, *J* = 8.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 128.70, 129.24, 129.65, 130.29, 130.37, 139.55, 141.68, 153.90. Anal. Calcd for $C_{20}H_{14}N_2$: C 85.08, H 5.00, N 9.92%. Found: C 84.88, H 4.95, N 9.95%; MS (EI), *m/z* (rel. intensity *%*) 158 (M^+, 65), 116 (100), 76 (40), 50 (50). HRMS (EI) Calcd. for $C_{20}H_{14}N_2$ $[M]^+$, 282.1000, Found 282.1006.

6-Methyl-2,3-diphenylquinoxaline (6): M. P.: 116-117°C (lit. [34] 117-118°C); IR (KBr) ν_{max}/cm^{-1}: 3065, 1660, 1595,

1210, 874, 717, 640; ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 2.65 (s, 3H), 7.36 (m, 6H), 7.53 (m, 4H), 7.64 (d, 1H, *J* = 8.5 Hz), 8.02 (s, 1H), 8.14 (d, 1H, *J* = 8.5 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 22.02, 127.68, 128.30, 128.51, 128.88, 128.97, 129.89, 129.95, 132.68, 138.55, 138.68, 139.48, 140.80, 141.02, 152.48, 153.07. Anal. Calcd for $C_{21}H_{16}N_2$: C 85.11, H 5.44, N 9.45%. Found: C 85.07, H 5.40, N 9.46%; MS (EI), *m/z* (rel. intensity *%*) 172 (M^+, 100), 130 (90), 89 (45), 50 (20). HRMS (EI) Calcd. for $C_{21}H_{16}N_2$ $[M]^+$, 296.1000, Found 296.1007.

6,7-Dimethyl-2,3-diphenylquinoxaline (7): M. P.: 172-174°C (lit. [34] 172°C); IR (KBr) ν_{max}/cm^{-1}: 3428, 2913, 1610, 1448, 1335, 823; ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 2.53 (s, 6H), 7.32 (m, 6H), 7.50 (d, 4H, *J* = 7.6 Hz, *J* = 1.6 Hz), 7.90 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 20.85, 128.60, 128.66, 128.94, 130.26, 139.85, 140.66, 140.93, 152.95. Anal. Calcd for $C_{22}H_{18}N_2$: C 85.13, H 5.85, N 9.03%. Found: C 85.09, H 5.80, N 9.06%; HRMS (EI) Calcd. for $C_{22}H_{18}N_2$ $[M]^+$, 310.1001, Found 310.1008.

6-Nitro-2,3-diphenylquinoxaline (8): M. P.: 192-193°C (lit. [34] 193-194°C); IR (KBr) ν_{max}/cm^{-1}: 3057, 2935, 1621, 1341, 1135, 699; ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.42 (m, 6H), 7.57 (m, 4H), 8.32 (d, 1H, *J* = 8.0 Hz), 8.56 (m, 1H), 9.10 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 124.40, 126.75, 129.54, 129.60, 130.80, 130.92, 130.99, 131.07, 131.90, 139.17, 139.23, 141.09, 144.70, 148.95, 156.80, 157.42. Anal. Calcd for $C_{20}H_{13}N_3O_2$: C 73.38, H 4.00, N 12.84%. Found: C 73.35, H 3.98, N 12.86%; MS (EI), *m/z* (rel. intensity *%*) 203 (M+, 100), 162 (30), 116 (50), 75 (15). HRMS (EI) Calcd. for $C_{20}H_{13}N_3O_2$ $[M]^+$, 327.1000, Found 327.1010.

6-Chloro-2,3-diphenylquinoxaline (9): M. P.: 113-114 °C (lit. [43] 115-116°C); IR (KBr) ν_{max}/cm^{-1}: 3395, 3056, 1393, 1330, 697; ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.40 (m, 6H), 7.57 (m, 4H), 7.73 (d, 1H, *J* = 8.9 Hz, *J* = 2.3 Hz), 8.13 (d, 1H, *J* = 8.9 Hz), 8.22 (d, 1H, *J* = 2.3 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 128.50, 128.75, 129.46, 129.53, 130.25, 130.29, 130.88, 131.37, 136.08, 139.10, 139.18, 140.15, 141.94, 154.03, 154.76; Anal. Calcd for $C_{20}H_{13}ClN_2$: C 75.83, H 4.14, N 8.84%. Found: C 75.86, H 4.13, N 8.85%; MS (EI), *m/z* (rel. intensity *%*) 192 (M^+, 70), 151 (100), 110 (60), 75 (65). HRMS (EI) Calcd. for $C_{20}H_{13}ClN_2$ $[M]^+$, 316.1000, Found 316.1008.

2,3-Diphenyl-4a,5,6,7,8,8a-hexahydroquinoxaline (10): M. P.: 167-169°C (lit. [44] 167°C); IR (KBr) ν_{max}/cm^{-1}: 3055, 1541, 1345, 768, 729; ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 1.48 (m, 2H), 1.69 (m, 2H), 1.94 (m, 2H), 2.55 (m, 2H), 2.89 (m, 2H), 7.26 (m, 4H), 7.32 (m, 2H), 7.42 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 25.88, 33.96, 59.95, 128.45, 128.56, 129.88, 138.23, 160.10; Anal. Calcd for $C_{20}H_{20}N_2$: C 83.30, H 6.99, N 9.71%. Found: C 83.33, H 6.94, N 9.66%; HRMS (EI) Calcd. for $C_{20}H_{20}N_2$ $[M]^+$, 288.2001, Found 288.2007.

Dibenzo[a,c]phenazine (11): M. P.: 223-225°C (lit. [45] 224.8-225.7°C); IR (KBr) ν_{max}/cm^{-1}: 3065, 1660, 1594, 1210, 875, 719, 640; ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.56 (m, 6H), 8.11 (m, 2H), 8.32 (d, 2H, *J* = 8.0 Hz), 9.18 (d, 2H, *J* = 8.1 Hz); ^{113}C NMR (100 MHz, $CDCl_3$): δ_C 124.02, 127.35, 129.04, 130.51, 130.80, 131.43, 133.23, 143.25, 143.51; Anal. Calcd for $C_{20}H_{12}N_2$: C 85.69, H 4.31, N 9.99%. Found: C 85.66, H 4.27, N 9.96%; HRMS (EI) Calcd. for $C_{20}H_{12}N_2$ $[M]^+$, 280.1002, Found 280.1009.

11-Methyldibenzo[a,c]phenazine (12): mp 208-210°C (lit. [34] 209-211°C); ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 2.45 (s, 3H), 7.48 (m, 5H), 7.85 (s, 1H), 7.98 (d, 1H, *J* = 8.0 Hz), 8.31 (d, 2H, *J* = 8.0 Hz), 9.14 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 23.20, 123.97, 127.18, 127.29, 128.92, 129.10, 130.05, 131.07, 131.20, 131.45, 131.49, 132.88, 133.05, 133.45, 141.42, 141.80, 142.73, 143.27, 143.29. Anal. Calcd for $C_{21}H_{14}N_2$: C 85.69, H 4.79, N 9.52%. Found: C 85.67, H 4.82, N 9.54%; HRMS (EI) Calcd. for $C_{21}H_{14}N_2$ $[M]^+$, 294.1001, Found 294.1010.

Acenaphtho[1,2-b]quinoxaline (13): M. P.: 238-240°C (lit. [45] 239.5-241.3°C); ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.54 (m, 4H), 7.89 (d, 2H, *J* = 8.4 Hz), 8.19 (m, 2H), 8.20 (d, 2H, *J* = 6.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 122.95, 129.77, 130.35, 130.59, 130.74, 131.12, 132.92, 137.61, 142.39, 155.19. Anal. Calcd for $C_{18}H_{10}N_2$: C 85.02, H 3.96, N 11.02%. Found: C 85.05, H 3.91, N 11.05%; HRMS (EI) Calcd. for $C_{18}H_{10}N_2$ $[M]^+$, 254.1002, Found 254.1005.

9,10-Dimethylacenaphtho[1,2-b]quinoxaline (14): M. P.: 304-306°C (lit. [43] 304-306°C); ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 2.50 (s, 6H), 7.79 (m, 2H), 7.89 (s, 2H), 8.04 (m, 2H), 8.33 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 20.2, 121.4, 127.8, 128.0, 128.6, 128.9, 129.4, 139.5, 140.1, 148.5, 153.5. Anal. Calcd for $C_{20}H_{14}N_2$: C 85.08, H 5.00, N 9.92%. Found: C 85.04, H 5.04, N 9.97%; HRMS (EI) Calcd. for $C_{20}H_{14}N_2$ $[M]^+$, 282.1003, Found 282.1007.

9-Methylacenaphtho[1,2-b]quinoxaline (15): M. P.>300°C (lit. [45,38] >300°C); ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 2.60 (s, 3H), 7.57 (d, 1H, *J* = 8.25 Hz), 7.78 (t, 2H, *J* = 7.5 Hz), 7.97 (s, 1H), 8.05 (m, 3H), 8.35 (t, 2H, *J* = 6.3 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 22.18, 121.97, 122.14, 129.01, 129.03, 129.21, 129.53, 129.60, 129.75, 130.39, 131.70, 132.44, 136.69, 140.06, 140.12, 141.73, 153.78, 154.49. Anal. Calcd for $C_{19}H_{12}N_2$: C 85.05, H 4.51, N 10.44%. Found: C 85.07, H 4.49, N 10.40%; HRMS (EI) Calcd. for $C_{19}H_{12}N_2$ $[M]^+$, 268.1000, Found 268.1009.

6,7-Dimethyl-2-phenylquinoxaline (16): M.P.: 127-129°C (lit. [35] 128-129°C); ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 2.55 (s, 6H), 7.57 (t, 1H, *J* = 7.1 Hz), 7.59 (t, 2H, *J* = 7.1 Hz), 7.88 (s, 1H), 7.95 (s, 1H), 8.20 (d, 2H, *J* = 7.2 Hz), 9.25 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 20.76, 20.77, 127.82, 128.59, 129.10, 129.48, 130.26, 137.59, 140.50, 141.03, 141.18, 141.68, 142.83, 151.44. Anal. Calcd for $C_{16}H_{14}N_2$: C 82.02, H 6.02, N 11.96%. Found: C 82.06, H 5.97, N 11.93%; HRMS (EI) Calcd. for $C_{16}H_{14}N_2$ $[M]^+$, 234.1000, Found 234.1007.

2,3-Di(furan-2-yl)-6-nitroquinoxaline (17): M. P.: 165-167°C (lit. [42]); IR (KBr) ν_{max}/cm^{-1}: 3389, 1575, 1523, 1478, 1339, 749; ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.97 (d, *J* = 2.4 Hz, 1H), 8.45 (d, *J* = 9.2, 2.5 Hz, 1H), 8.20 (d, *J* = 9.2 Hz, 1H), 7.66 (m, 2H), 6.85 (d, *J* = 16.4, 3.5 Hz, 2H), 6.63 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 149.80, 149.75, 147.58, 145.14, 144.66, 144.34, 143.85, 142.63, 138.88, 130.12, 124.99, 123.99, 123.27, 115.05, 114.19, 112.10,

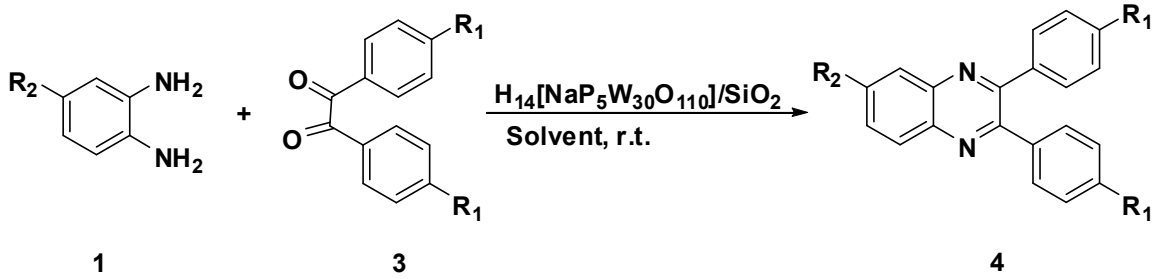
111.96. Anal. Calcd for $C_{16}H_9N_3O_4$: C 62.54, H 2.95, N 13.68%. Found: C 62.50, H 2.93, N 13.66%; HRMS (EI) Calcd. for $C_{16}H_9N_3O_4$ $[M]^+$, 307.1000, Found 307.1006.

6-bromo-2,3-di(furan-2-yl)quinoxaline (18): M. P.: 134-135°C (lit. [45]); IR (KBr) ν_{max}/cm^{-1}: 3110, 1570, 1478, 1412, 1323, 758. ^1H NMR (400 MHz, $CDCl_3$): δ_H 9.04 (d, J = 2.4 Hz, 1H), 8.55 (d, J = 2.4 Hz, 1H), 7.60 (m, 2H), 7.03 (d, J = 3.5 Hz, 1H), 6.75 (d, J = 3.5 Hz, 1H), 6.57 (m,2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 154.93, 150.00, 149.78, 147.16, 144.75, 144.66, 143.44, 138.63, 135.65, 120.77, 114.76, 114.35, 112.09, 111.85. Anal. Calcd for $C_{16}H_9BrN_2O_2$: C 56.33, H 2.66, N 8.21%. Found: C 56.30, H 2.63, N 8.22%; HRMS (EI) Calcd. for $C_{16}H_9BrN_2O_2$ $[M]^+$, 340.1000, Found 340.1007.

2,3-Diethyl-6-nitroquinoxaline (19): M. P.: 97-100°C (lit. [45]; IR (KBr) ν_{max}/cm^{-1}: 3433, 2975, 1614, 1524, 1339, 1275, 739; ^1H NMR (400 MHz, $CDCl_3$): δ_H 8.77 (d, J = 2.5 Hz, 1H), 8.32 (d, J = 9.1, 2.5 Hz, 1H), 8.03 (d, J = 9.1 Hz, 1H), 3.05 (q, J = 7.4 Hz, 4H), 1.40 (t, J = 7.4, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C 160.40, 159.43, 146.52, 143.19, 139.31, 129.65, 124.60, 121.61, 28.14, 27.90, 11.30, 11.25. Anal. Calcd for $C_{12}H_{13}N_3O_2$: C 62.33, H 5.67, N 18.17%. Found: C 62.30, H 5.64, N 18.19%; HRMS (EI) Calcd. for $C_{12}H_{13}N_3O_2$ $[M]^+$, 231.1001, Found 231.1006.

3. Results and Discussion

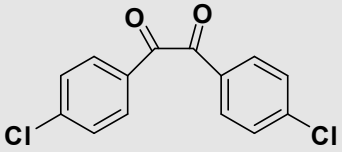
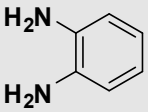
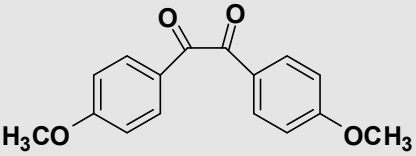
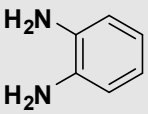
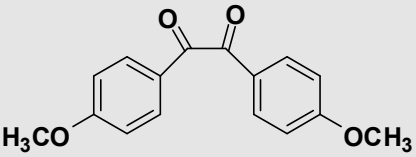
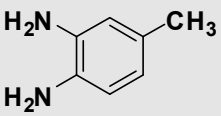
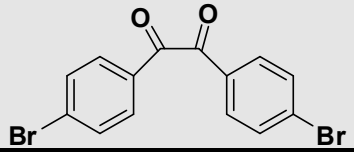
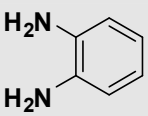
We became interested in the development of a new, efficient and practical method to synthesize quinoxalines under mild conditions using silica supported Preyssler heteropolyacids as a catalyst (Scheme 1).

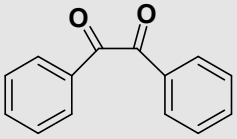
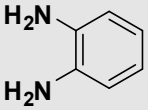
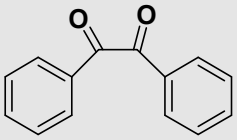
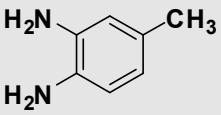
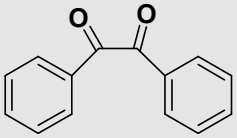
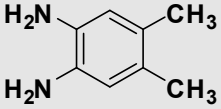
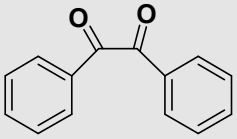
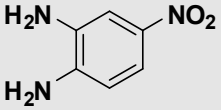
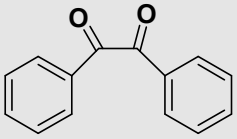
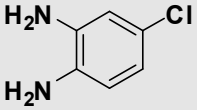
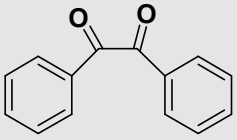
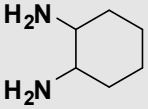
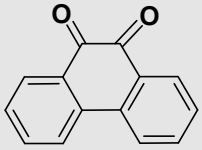
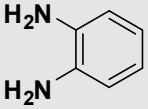
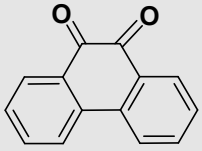
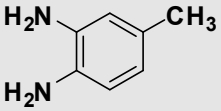
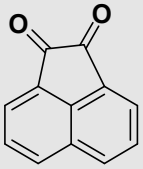
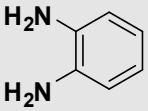
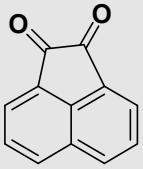
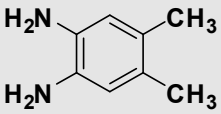
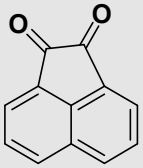
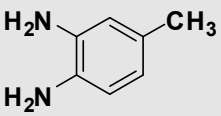
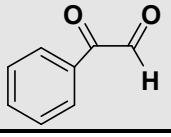
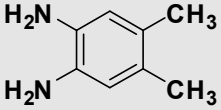


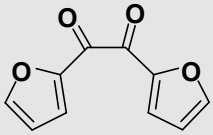
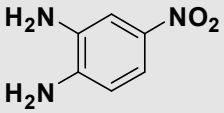
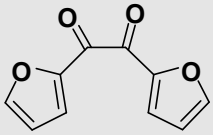
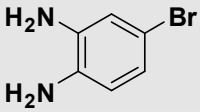
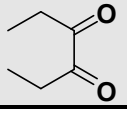
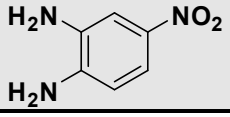
Scheme 1. *Synthesis of 2,3-diphenylquinoxalines catalyzed by silica supported Preyssler heteropolyacid, $H_{14}[NaP_5W_{30}O_{110}]/SiO_2$.*

Initial studies focused on the screening of the solvents, bases as well as catalyst loading with the reaction of benzil and *o*-phenylenediamine as the model reaction at room temperature. Efforts were directed towards the evaluation of the synthesis of quinoxalines in the presence of silica Preyssler heteropolyacid catalys and at room temperature. Thus, the efficacy of various solvents was investigated in the model reaction using benzil with *o*-phenylenediamine under room temperature and the results are summarized in Table 1.

Table 1. *Synthesis of quinoxaline derivatives catalyzed by silica supported Preyssler heteropolyacid, $H_{14}[NaP_5W_{30}O_{110}]/SiO_2$(50%) at room temperature.*

Entry	Dicarbonyl Compound	Diamine	Time (min)	[a]Yield (%)
1			185	91
2			35	88
3			35	89
4			24	91

Entry	Dicarbonyl Compound	Diamine	Time (min)	[a]Yield (%)
5			6	98
6			7	96
7			12	92
8			168	91
9			17	90
10			18	92
11			4	96
12			9	94
13			7	97
14			15	92
15			9	93
16			12	92.5

Entry	Dicarbonyl Compound	Diamine	Time (min)	[a]Yield (%)
17			20	91
18			22	93
19			15	95

[a]Isolated yield.

3.1. Effects of Various Solvents

We performed this reaction with aprotic solvents (such as CCl_4, $CHCl_3$, CH_2Cl_2, CH_3CN, $C_2H_5COOCH_3$, DMSO, DMF and THF) and protic solvents (such as H_2O, CH_3OH and C_2H_5OH). Almost all of the solvents (such as CCl_4 (yield 90%), $CHCl_3$ (91%), CH_3CN (95%), CH_2Cl_2 (94%), THF (84%), DMSO (91%), DMF (82%) and $C_2H_5COOCH_3$ (96%)) with the exception of H_2O (40%) afforded the desired products in good yields. The protic solvent CH_3OH (97%) and C_2H_5OH (98%) came out as a superior solvent in this transformation.It can easily be seen that the condensation reaction proceeded smoothly in the chosen solvent system and gave reasonable good to excellent yields, ranging from 85% to 96%. In the case of 1,2-diketones, either electron-withdrawing or electron-donating substituents (R_1= OCH_3, Cl, Br) on the aromatic ring gave slightly longer reaction times in comparison with R_1= H (Table 1, entries 1-4, 8). However, for substituents on *o*-phenylenediamine (R_2), electron-donating substituents (such as CH_3) reacted in shorter reaction times in comparison with electron-withdrawing groups (such as NO_2). So, the order of the reactivity for condensation reaction was found to be: H > CH_3 > Cl > NO_2 (Table 2).

Table 2. *Effects of solvents on the reaction of benzil (1) and o-phenylenediamine (2), in presence of $H_{14}[NaP_5W_{30}O_{110}]/SiO_2$(50%) at room temperature, (Table (1), entry (5)).*

Entry	Solvent	[a,b]Yield (%)
1	CCl_4	90
2	$CHCl_3$	91
3	CH_2Cl_2	94
4	CH_3CN	95
5	CH_3OH	97
6	C_2H_5OH	98
7	THF	84
8	DMSO	91
9	DMF	82
10	H_2O	40
11	$C_2H_5COOCH_3$	96

[a] All reactions were performed at 1 mmol of 1, 2-diketone (1), dicarbonyl compound (2) and Preysslet catalyst (0.05 g) and 5 mL of solvent. [b] Isolated yields.

On the other hand, some heterocyclic 1,2-diketone such as furyl was subjected for condensation reaction and the desired products was obtained in excellent yields (Table 1, entries 17-18). When aliphatic 1,2-diketone, such as 3,4-hexanedione was used as substrate, the desired products were also obtained with excellent yield (Table 1, entry 19).

3.2. Effects of Catalyst Loading

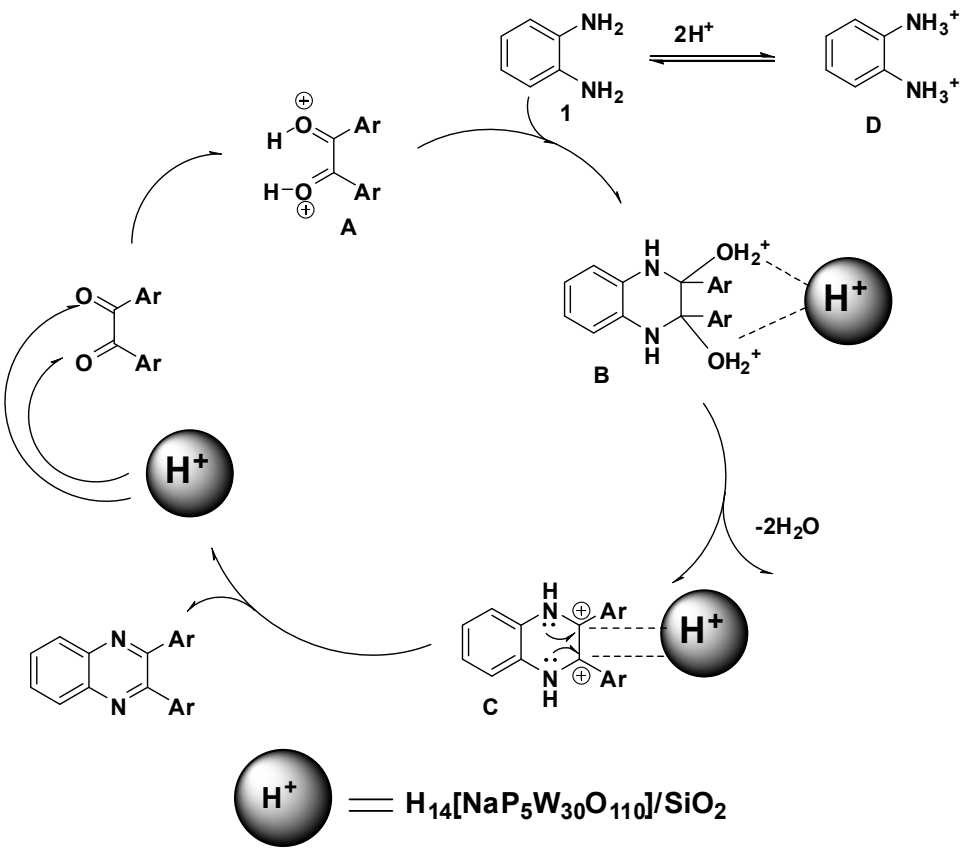
The effect of catalyst loading on the condensation reaction between benzil and *o*-phenylenediamine was also studied. This results show clearly that silica supported Preyssler heteropolyacid is an effective catalyst for this condensation in Table (3).

Table 3. *Effects of Preyssler catalyst loadings in the synthesis of 2,3-Diphenylquinoxaline (Table (1), entry (5)) under room temperature and ethanol as solvent.*

Entry	Catalyst	[a]Yield (%)
1	$H_{14}[NaP_5W_{30}O_{110}]/SiO_2$ (10%)	48
2	$H_{14}[NaP_5W_{30}O_{110}]/SiO_2$ (20%)	57
3	$H_{14}[NaP_5W_{30}O_{110}]/SiO_2$ (30%)	69
4	$H_{14}[NaP_5W_{30}O_{110}]/SiO_2$ (40%)	82
5	$H_{14}[NaP_5W_{30}O_{110}]/SiO_2$ (50%)	98

[a]Isolated yield.

The reaction is assumed to follow the regular mechanism of acid-catalyzed condensation reactions [29], with silica supported Preyssler heteropolyacid acting as an acid in the protonation of the diketone and also playing a role in promoting the dehydration to give a carbocationic intermediate as shown in Scheme 2: (i) coordination of a 1,2-dicarbonyl onto acid sites from silica supported Preyssler heteropolyacid, followed by (ii) the nucleophilic attack on the carbonyl C providing intermediate A, (iii) dehydration to give a carbocation intermediate and (iv) elimination of a proton to give the quinoxaline product.



Scheme 2. *Proposed mechanism for the condensation reaction of 1,2-diamines with 1,2-dicarbonyl compounds catalyzed by silica supported Preyssler heteropolyacid, $H_{14}[NaP_5W_{30}O_{110}]/SiO_2(50\%)$.*

3.3. Reusability of the Catalyst

In order to know whether the catalysts would succumb to poisoning and lose of catalytic activity during the reaction, the catalyst was recovered after the reaction and reused as catalyst in the esterification reactions. These studies are performed with all of forms of silica-supported Preyssler heteropolyacid, $H_{14}[NaP_5W_{30}O_{110}]/SiO_2(50\%)$ catalyst. We have found that Preyssler catalyst can be reused several times without any appreciable loss of activity. IR spectra of the resulting solids indicate that the catalyst can be recovered without structural degradation. The several time recoveries had only slightly decreased the catalytic activity, pointing to the stability and retention capability of this useful polyanion. Even after five runs for the reaction, the catalytic activity of $H_{14}[NaP_5W_{30}O_{110}]/SiO_2(50\%)$ was almost the same as that of the freshly used catalyst. Ease of recycling of the catalyst is one of the most advantages of our method. For the reaction of benzene-1,2-diamine with benzil no significant loss of the product yield was observed when silica supported Preyssler heteropolyacid was used after five times recycling. The results were summarized in Table 4.

Table 4. *The Results of the Condensation of Benzene-1,2-diamine with Benzil in the Presence of Recycled silica supported Preyssler heteropolyacid, $H_{14}[NaP_5W_{30}O_{110}]/SiO_2(50\%)$.*

Entry	Run	Time (min)	[a]Yield (%)
1	1	6	97
2	2	6	96
3	3	6	93
4	4	6	90
5	5	6	88

[a]Isolated yield.

4. Conclusion

In conclusion, this work shows that silica supported Preyssler heteropolyacid, $H_{14}[NaP_5W_{30}O_{110}]/SiO_2(50\%)$, prepared from commercially available and relatively cheap starting materials by a simple transformation and to give quinoxaline derivatives in good to excellent yield. It could also be recovered and reused for more than five reaction cycles without noticeable loss of reactivity. The advantages of this method are extremely mild reaction conditions, short reaction times, high yields, simple experimental and isolation procedures, and compliance with the green chemistry protocols.

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