IRANIAN JOURNAL OF CATALYSIS

γ-Fe₂O₃@SiO₂-PW₁₂ nanoparticles: Highly efficient catalysts for the synthesis of pyrazoline derivatives

Hamid Aliyan[*a,b], Razieh Fazaeli[a], Nafiseh Tajsaeed[a]

[a]*Department of Chemistry, Shahreza Branch, Islamic Azad University, 86145-311, Iran.*
[b]*Razi Chemistry Research Center, Shahreza Branch, Islamic Azad University, Iran*

ABSTRACT

A new type of magnetically-recoverable catalyst was synthesized by the immobilization of $H_3PW_{12}O_{40}$ on the surface of silica-encapsulated γ-Fe₂O₃ nanoparticles. A series of novel 1,3,5-triaryl pyrazoline derivatives has been synthesized by the reaction of chalcone and phenylhydrazine in the presence of the γ-Fe₂O₃@SiO₂-PW₁₂ nanoparticles, in high yields. The structures of compounds obtained were determined by IR and ^{1}H NMR spectra. γ-Fe₂O₃@SiO₂-PW₁₂ was recycled and no appreciable change in activity was noticed after three cycles.

Keywords: Silica-encapsulated γ-Fe₂O₃ nanoparticles, Heterogeneous catalysis, Pyrazoline, Phenyl hydrazine, Chalcone.

1. Introduction

Pyrazolines are well known, and important nitrogen-containing five-membered heterocyclic compounds and various methods have been worked out for their synthesis [1]. Pyrazoline derivatives are attracting increasing interest of many researchers, not only in medicinal chemistry because of their bioactivity such as antimicrobial [2], antiamoebic [3], antinociceptive [4], anticancer [5], antidepressant [6] and anti-inflammatory [7], but also in conjugated fluorescent dyes emitting blue fluorescence with high fluorescence quantum yield [8] and electroluminescence fields [9]. Among various pyrazoline derivatives, 1,3,5-triaryl-2-pyrazolines seem to be the most frequently studied pyrazoline type compounds. Several catalysts have been developed for the preparation of these heterocycles, including sodium acetate-acetic acid aqueous solution under ultrasound irradiation [10], hot acetic acid solution [11], K_2CO_3-mediated microwave irradiation [12], $H_3PW_{12}O_{40}$ [13] Tungstophosphoric Acid Supported on Highly Organosoluble Polyamide (PW₁₂/PA) [14] and Bifunctional Brønsted Acidic Ionic Liquid [15].

Hydrogen forms (or free acids) of heteropoly acids (HPAs) usually have low surface areas (the drawback

*Corresponding author: E-mail: aliyan@iaush.ac.ir
Tel: +98 321 3232706-7; Fax: +98 321 3232701

to the $H_3PW_{12}O_{40}$ (PW₁₂) is their low surface area, 1-5 $m^2 g^{-1}$, and low porosity (< 0.1 cm^3 g^{-1}). Supported HPA catalysts have much greater surface areas. Many attempts have been made to disperse and fix HPA catalysts on various supports. Support materials such as silica, carbon, and organic resins have been applied with varying levels of success, with new supporting materials and methods being actively pursued [16,17]. Although the structure and composition of the supported HPAs are sometimes uncertain, high catalytic activities are often observed and separation made easier. For various reasons, such as efficiency, better accessibility to the active sites, cost, depositing on a support is currently favored [18,19].

The immobilization of PW₁₂ on silica-coated γ-Fe₂O₃ NPs (designed as γ-Fe₂O₃@SiO₂-PW₁₂) can be employed to derive a novel heterogeneous catalyst system that possesses both a high separation efficiency and a relatively high surface area to maximize catalyst loading and activity. Certainly, the use of environmentally benign solvents has been another key research area of green chemistry, with great advances being seen in aqueous catalysis. Along this line, we synthesized γ-Fe₂O₃@SiO₂-PW₁₂ as a novel nanomagnetically-recoverable catalyst and assessed its catalytic activity for the synthesis of 1,3,5-triaryl-2-pyrazolines derivatives (Scheme 1).

Scheme 1. Synthesis of 1,3-5-triaryl-2-pyrazolines (**3**).

2. Experimental

2.1. Preparation of the catalyst

The γ-Fe_2O_3 NPs were synthesized by a chemical coprecipitation technique of ferric and ferrous ions in an alkaline solution. $FeCl_2$. $4H_2O$ (2.0 g) and $FeCl_3$.$6H_2O$ (5.4 g) were dissolved in water (20 mL) separately, followed by the two iron salt solutions being mixed under vigorous stirring. An NH_4OH solution (0.6 M, 200 mL) was then added to the stirring mixture at room temperature, immediately followed by the addition of a concentrated NH_4OH solution (25% w/w, 30 mL) to maintain the reaction pH between 11 and 12. The resulting black dispersion was continuously stirred for 1 h at room temperature and then heated to reflux for 1 h to yield a brown dispersion. The MNPs were then purified by a four times repeated centrifugation (4000–6000 rpm, 30 min), decantation and redispersion cycle until a stable brown magnetic dispersion (pH 9.2) was obtained (mean diameter = 65.5 nm). Coating of a layer of silica on the surface of the γ-Fe_2O_3 NPs was achieved by pre-mixing (ultrasonic) a dispersion of the purified NPs (8.5% w/w, 20 mL) obtained previously with ethanol (80 mL) for 1 h at 40 ◦C. A concentrated ammonia solution was added and the resulting mixture stirred at 40 ◦C for 30 min. Subsequently, TEOS (1.0mL) was charged to the reaction vessel and the mixture continuously stirred at 40 ◦C for 24 h. The silicacoated NPs were collected using a permanent magnet, followed by washing three times with ethanol, diethyl ether and drying in a vacuum for 24 h (mean diameter = 79.3 nm). 0.7 g of PW_{12} was dissolved in 5mL of dry methanol. This solution was added dropwise to a suspension of 1.0 g γ-Fe_2O_3@SiO_2 in methanol (50 mL) while being dispersed by sonication. The mixture was heated at 70 ◦C for 72 h under vacuum while being mechanically stirred to obtain γ-Fe_2O_3@SiO_2-PW_{12} NPs. The catalyst was collected by a permanent magnet and dried in a vacuum overnight. (0.005 g). The reaction mixture was vigorously stirred for the period of time listed in Table 2. The progress of the reaction was monitored by TLC. When the reaction was complete, γ-Fe_2O_3@SiO_2-PW_{12} could be placed on the side wall of the reaction vessel with the aid of an external magnet, and water was removed from the mixture to leave a residue (including the product and catalyst). Then, the product was dissolved in ethanol and the catalyst easily separated from the product by attaching an external magnet onto the reaction vessel, followed by decantation of the product solution. This solution was concentrated at roomtemperature to generate the crude product. The crude products were purified either by crystallization from ethanol or by column chromatography on silica gel using ethyl acetate/hexane as the eluent. All products were identified by comparing of their spectral data with those of authentic samples [20,21].

2.2. General procedure for the synthesis of chalcone (Benzylideneacetophenone)

The chalcone (Benzylideneacetophenone) was prepared as described previously [22].

2.3. Typical procedure for the synthesis of 1,3,5-triaryl pyrazoline

The following components were added to the reaction vessels: chalcone (1 mmol), phenylhydrazine (1 mmol) and γ-Fe_2O_3@SiO_2-PW_{12} (0.03 mmol). Progress of the reaction was monitored by TLC. At the end of the reaction the produced mixture was washed off the vessel using EtOAc (20 ml) and then was filtered. The filtrate was dried ($MgSO_4$) and evaporated. The crude product was purified by column chromatography to provide 1,3,5-triaryl pyrazoline.

2.4. Selected spectroscopic data

*5-(4-Methylphenyl)-1,3-diphenyl-2-pyrazoline (3*a):^{1}H NMR ($CDCl_3$): δ 2.34 (s, 3H, CH_3), 3.14 (dd, *J*=7.1, 17.0 Hz, 1H), 3.85 (dd, *J*=12.1, 17.0 Hz, 1H), 5.27 (dd, J=6.9, 12 Hz, 1H) 6.77-7.75 (m, 14H) ppm. Anal. calcd. for $C_{22}H_{20}N_2$: C 84.62, H 6.41, N 8.97; found C 84.61, H 6.43, N 9.00. ^{13}C NMR ($CDCl_3$): δ 21.68, 44.09, 64.73, 113.69, 119.47, 126.23, 128.43, 128.88, 129.34, 129.57, 130.19, 133.07, 137.67, 141.53, 145.43, 147.17. IR (KBr) ν $_{max}$: 1117, 1499, 1593 cm^{-1}.

5-(4-Chlorophenyl)-1,3-Diphenyl-2-Pyrazoline (3b):^{1}H- NMR (CDCl$_3$): δ3.04 (dd, *J* = 7.4, 17.6 Hz, 1H), 3.77 (dd, *J* = 11.6, 17.6 Hz, 1H), 5.67 (dd, *J* = 7.4, 11.6 Hz, 1H), 6.71–7.64 (m, 14H); Anal. Calcd. for C$_{21}$H$_{17}$ClN$_2$: C, 75.78; H, 5.15; N, 8.41. Found: C, 75.69; H; 5.10; N, 8.49%. ^{13}CNMR (CDCl$_3$): δ 43.4, 63.8, 113.4, 119.4, 125.7, 127.3, 128.5, 128.7, 128.9, 129.3, 129.9, 132.5, 133.3, 141.1, 144.6, 146.7. IR (KBr) ν $_{max}$: 1123, 1495, 1598 cm^{-1}.

5-(3-Chlorophenyl)-1,3-Diphenyl-2-Pyrazoline (3c):
^{1}H NMR (CDCl$_3$): δ 3.08 (dd, *J*=6.8, 17.0 Hz, 1H), 3.43 (dd, *J*=12.2, 17.2 Hz, 1H), 5.63 (dd, *J*=6.9, 12.4 Hz, 1H) 6.85-7.81 (m, 14H) ppm. Anal. calcd. for C$_{21}$H$_{17}$N$_2$Cl: C 85.85, H 5.72, N 9.43; found C 85.79, H 5.70, N 9.41. ^{13}C NMR (CDCl$_3$): δ 42.37, 61.54, 113.58, 119.60, 124.44, 127.79, 128.07, 128.92, 129.18, 129.48, 130.67, 132.53, 133.04, 135.04, 139.67, 144.84, 147.53. IR (KBr) ν max: 1127, 1501, 1593 cm^{-1}.

5-(2-Chlorophenyl)-1,3-Diphenyl-2-Pyrazoline (3d):
^{1}H NMR (CDCl$_3$): δ3.06 (dd, *J* = 4.8, 17.6 Hz, 1H), 3.96 (dd, *J* =11.2, 17.7 Hz, 1H), 5.64 (dd, *J* = 4.7, 11.0 Hz, 1H), 6.76–7.74 (m, 14H); Anal. Calcd. for C$_{21}$H$_{17}$ClN$_2$: C, 75.78; H, 5.15; N, 8.41. Found: C, 75.83; H, 5.23; N, 8.38%.^{13}C NMR (CDCl$_3$): δ 41.9, 61.5, 113.3, 119.2, 125.9, 127.5, 127.9, 128.3, 128.5, 128.8, 129.3. 129.8, 131.4, 132.2, 139.5, 144.6, 147.4. IR (KBr) ν $_{max}$: 1120, 1497, 1595 cm^{-1}.

5-(2,4-Dichlorophenyl)-1,3-Diphenyl-2-Pyrazoline (3e):
^{1}H NMR (CDCl$_3$): δ 3.02 (dd, *J* = 6.6, 17.6 Hz, 1H), 3.97 (dd, *J* =12.5, 17.5 Hz, 1H), 5.59 (dd, *J* = 6.6, 12.2 Hz, 1H), 6.69–7.71 (m, 13H); Anal. Calcd. for C$_{21}$H$_{16}$Cl$_2$N$_2$: C, 68.67; H, 4.39; N, 7.62. Found: C, 68.73; H, 4.39; N, 7.71%. ^{13}CNMR (CDCl$_3$): δ 41.5, 60.9, 113.5, 119.5, 124.3, 125.6, 127.4, 127.7, 128.6, 128.5, 128.5, 129.2, 129.5, 132.1, 133.9, 137.7, 144.4, 147.5. IR (KBr) ν $_{max}$: 1118, 1503, 1589 cm^{-1}.

5-(3-Bromophenyl)-1,3-Diphenyl-2-Pyrazoline (3f): ^{1}H NMR (CDCl$_3$): δ3.08 (dd, *J*=7.1, 17.0 Hz, 1H), 3.35 (dd, *J*=12.1, 16.9 Hz, 1H), 5.68 (dd, *J*=6.9, 12.7 Hz, 1H) 6.80-7.75 (m, 14H) ppm. Anal. calcd. for C$_{21}$H$_{17}$N$_2$Br: C 85.85, H 5.72, N 9.43; found C 85.78, H 5.69, N 9.43. ^{13}C NMR (CDCl$_3$): δ 42.35, 60.47, 113.35, 119.50, 124.23, 127.94, 128.05, 129.06, 129.16, 129.35, 130.59, 132.41, 133.18, 139.66, 145.25, 147.14. IR (KBr) ν $_{max}$: 1126, 1502, 1598 cm^{-1}.

5-(4-Methoxyphenyl)-1,3-Diphenyl-2-Pyrazoline (3g): ^{1}H NMR (CDCl$_3$): δ 3.12 (dd, *J*=7.1, 17.1 Hz, 1H), 3.82 (s, 3H, OCH$_3$), 3.87 (dd, *J*=12.1, 16.9 Hz, 1H), 5.24 (dd, *J*=7.2, 12 Hz, 1H) 6.75-7.85 (m, 14H) ppm. Anal. calcd. for C$_{22}$H$_{20}$N$_2$O: C 84.62, H 6.41, N 8.97; found C 84.56, H 6.40, N 8.93. ^{13}C NMR (CDCl$_3$): δ 44.08, 55.64, 64.14, 113.72, 114.46, 119.54, 126.42, 127.91, 128.47, 128.89, 129.19, 130.56, 133.21, 135.03, 145.34, 147.17. FTIR (KBr) ν $_{max}$: 1120, 1261, 1512, 1597 cm^{-1}.

3-(4-Chlorophenyl)-1,5-Diphenyl-2-Pyrazoline (3h):
^{1}H NMR (DMSO): δ 3.15 (dd, *J*=7.1, 17.0 Hz, 1H), 3.87 (dd, *J*=12.2, 17.1 Hz, 1H), 5.33 (dd, *J*=7.3, 12.4 Hz, 1H) 6.83-7.67 (m, 14H) ppm. Anal. calcd. for C$_{21}$H$_{17}$N$_2$Cl: C 84.85, H 5.72, N 9.43; found C 84.81, H 5.77, N 9.47. ^{13}C NMR (DMSO): δ 42.39, 61.31, 113.53, 117.26, 126.83, 126.94, 128.64, 129.16, 129.39, 130.55, 132.17, 132.19, 136.05, 139.61, 143.73, 147.39. IR (KBr) ν $_{max}$: 1121, 1509, 1599 cm^{-1}.

3. Results and Discussion

3.1 Characterization of the γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$

The FTIR spectrum of the synthesized γ-Fe$_2$O$_3$ NPs shown the absorption bands at 449.5, 588.7, 637.8, 799.5 and 900 cm^{-1} [23]. Fig. 1a show the FT-IR spectra of the γ-Fe$_2$O$_3$@SiO$_2$ which are as same as reported previously [24]. These observations confirmed the synthesis of γ-Fe$_2$O$_3$@SiO$_2$. The transmission spectrum of γ-Fe$_2$O$_3$ @SiO$_2$ shows that the absorption band at 593 cm^{-1} could be related to the vibration of γ-Fe–O [25]. The bands at 1104 cm^{-1}, along with shoulder at 1199 and 461 cm^{-1}, are presumably due to asymmetric stretching and bending modes of Si–O–Si, respectively. The shoulder at 805 cm^{-1} may be assigned either to a symmetric stretching of Si–O–Si or a stretching vibration of Fe–O bonds. The characteristic band of Si–O–Fe appears at 686 cm^{-1} in this sample [26].
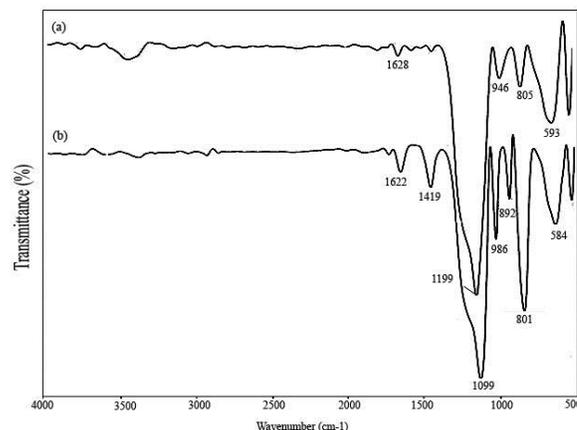
Fig. 1. FTIR spectra of (a) γ-Fe$_2$O$_3$@SiO$_2$ and (b) γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$.

PW$_{12}$ shows typical bands for absorptions at 1080 (P–O), 984 (W O), 896 and 814 (W–O–W) cm^{-1}. In γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$ (Fig. 1b), the characteristic bands are at the same wavenumbers, with a small shift according to the interaction with the support. The PW$_{12}$ band in the 1080 cm^{-1} zone is masked by the Si–O–Si absorption band in the γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$ spectrum. Fig. 2 show the TEM image and size histogram for the γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$ NPs. The particle size distribution from the TEM image shows that NPs are in the range 75–90 nm and that the mean diameter of the observable NPs is 68 nm.

3.2. Choice of reaction media and effect of the catalyst on the synthesis of 1,3,5-triaryl-2-pyrazolines derivatives

At first, the condensation reaction of chalcone and phenylhydrazine was performed in the presence of catalytic amount of the γ-Fe$_2$O$_3$ (Table 1, entry 1). The synthesis could not be achieved with high yield in the presence of the theγ-Fe$_2$O$_3$. To choose the most appropriate medium in this heterocyclization reaction, synthesis of 1,3,5-triaryl-2-pyrazolines from the condensation of chalcone and phenylhydrazine in the presence of a catalytic amount of γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$ nanoparticleswere selected as a model reaction. It seems that alcoholic solvents (methanol and ethanol), CH$_2$Cl$_2$, CH$_3$CN, and CHCl$_3$ gave good conversions. Clearly, ethanol stands out as the solvent of choice, with its fast conversion, high yield and easy removal. To establish the optimal conditions, a set of experiments varying the amount of the catalyst, and temperature (Table 1) were carried out. Using 3 mol% of catalyst to chalcone shows the best result for this reaction in EtOH at 45 °C. These conditions were applied to a series of substituted aromatic aldehydes.

On the basis of the above results, to extend the scope and generality of this method, several structurally diverse chalcones and phenylhydrazines were cyclized to give 1,3,5-triaryl 2-pyrazoline by γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$ NP. The results are listed in Table 2. It could be seen that the reactions proceeded well with all substrates, but substrates with electron-donating groups were generally more reactive than those with electron-withdrawing groups.

A reasonable pathway for the reaction of chalcone with phenylhydrazine in the presence of PW$_{12}$/PA is also presented by Scheme 2.

In order to show the effect of the catalytic activity of γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$ nanocrystals in the synthesis of
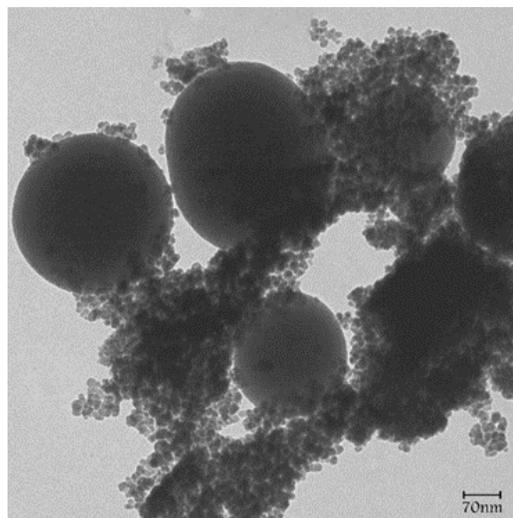
Fig. 2. TEM image for γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$.

1,3,5-triaryl-2-pyrazoline derivatives, all reactions were repeated with the same reaction conditions in the presence of H$_3$PW$_{12}$O$_{40}$ [13] and PW$_{12}$/PA [14] as catalysts. The obtained results showed that the turnover frequencies (TOF) in the synthesis of 1,3,5-triarylpyrazoline derivatives catalyzed by CsHPWnanocrystals was higher than the PW$_{12}$ and γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$. One explanation for this behavior is that γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$ nanocrystals have high specific structure areas.

In order to show the merit of the present work in comparison with recently reported protocols [13,14, 26], we compared the results with respect to the amounts of the catalysts used, reaction times and yields of the products (Table 3). Comparison of γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$ with these catalysts for the synthesis of 1,3,5-triaryl pyrazoline show that activity of γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$ seems to be higher than or equal with other known catalysts (Table 3).

3.3. Rcovery

Magnetic separation provides a very convenient approach for removing and recycling magnetic composites by applying an added magnetic field. The separation of γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$ nanocatalyst from the reaction mixture becomes very easy owing to the superparamagnetic nature of Fe$_3$O$_4$ nanoparticles at room temperature. In the magnetic separation technique, the catalyst became adsorbed onto the magnetic stirring bar when the stirring was stopped. In our experiments, the reusability of the catalyst were examined by repetitive use of the catalyst. The wet catalyst was recycled and no appreciable change in activity was noticed after three cycles.

Table 1. Effect of different conditions in the reaction of chalcone with phenylhydrazine in 45 ^{o}C.[a]
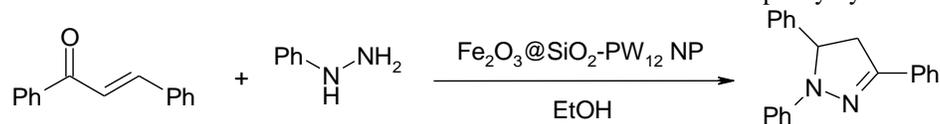
Entry	Catalyst	Catalyst (mol%)	Solvent	Temperature (^{o}C)	Yield (%)[b]
1	-	-	EtOH	45	<3
2	γ-Fe$_2$O$_3$	3	EtOH	45	11
3	PW$_{12}$@SiO$_2$	3	EtOH	45	23
4	γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$	2	EtOH	45	45
5	γ-Fe$_3$O$_4$@SiO$_2$-PW$_{12}$	3	EtOH	45	70
6	γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$	3	EtOH	45	98
7	γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$	4	EtOH	45	98
8	γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$[c]	3	EtOH	45	75
9	γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$[d]	3	EtOH	45	82
10	γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$	3	EtOH	r.t.	75
11	γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$	3	MeOH	45	80
12	γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$	3	CH$_3$CN	45	58
13	γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$	3	CH$_2$Cl$_2$	45	43

[a]Reaction conditions: chalcone (1 mmol), phenylhydrazine (1 mmol) and catalyst, in EtOH (5ml), after 1h, in 45°C.
[b]Isolated Yield.
[c]Chalcone/phenylhydrazine: 1/2
[d]Chalcone/phenylhydrazine: 1/3

Table 2. Synthesis of 1,3,5-triaryl-2-pyrazoline (TAP) derivatives in the presence of γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$ nanoparticles.[a]
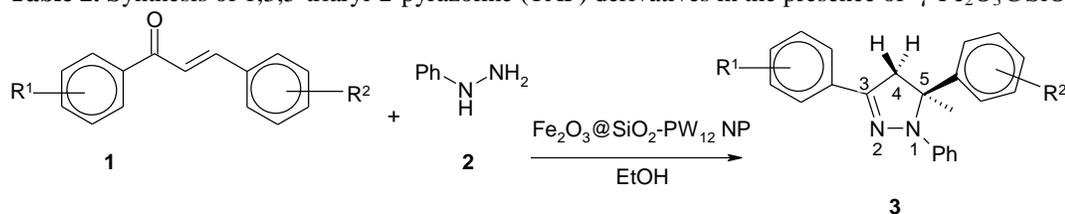
TAP	R$_1$	R$_2$	Yield (%)[b]	Mp(^{o}C)	
				Found	**Reported**
3a	H	4-Me	98	128-130	128-130 [10]
3b	H	4-Cl	92	136-137	133-134[11]
3c	H	3-Cl	90	131-133	134-136[10]
3d	H	2-Cl	85	131-133	134-135[11]
3e	H	2,4-Cl$_2$	83	136-138	136-138 [11]
3f	H	3-Br	90	139-141	141-143[11]
3g	H	4-MeO	95	109-111	110-112[11]
3h	4-Cl	H	87	143-145	143-145[11]

[a]Reaction conditions: chalcone (1 mmol), phenylhydrazine (1 mmol) and γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$ (0.03 mmol), in EtOH, after 100 min.
[b]Isolated Yield
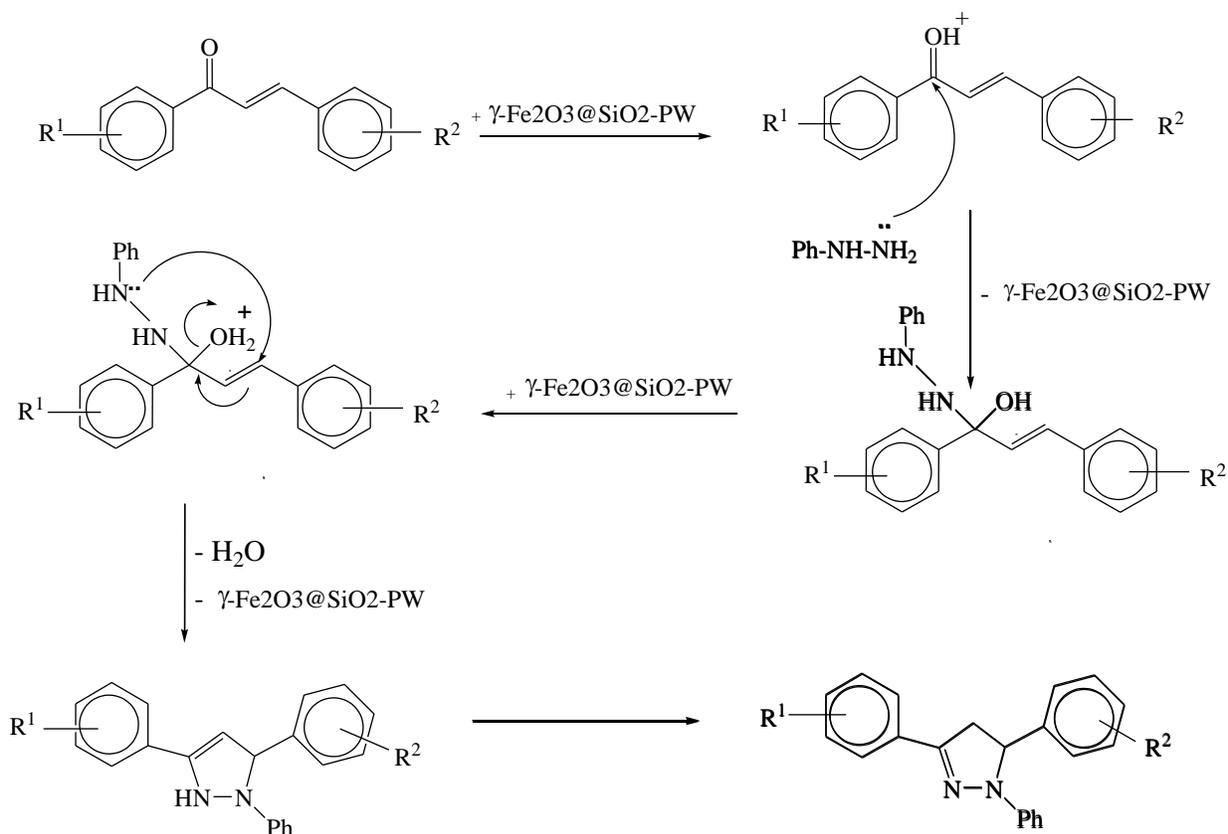
Scheme 2. Suggested mechanism for the reaction of chalcone with phenylhydrazine in the presence of γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$.

4. Conclusions

A series of γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$ catalysts were prepared by the wet impregnation method. This catalyst is a safe and magnetically recoverable heterogeneous system for promoting the synthesis of 1,3,5-triaryl pyrazoline. The advantages of this catalytic system is mild reaction conditions, short reaction times, high product yields, easy preparation of the catalysts, non-toxicity of the catalysts, simple and clean work-up of the desired products. In addition, the catalysts can be reused several times but they will be less active.

Acknowledgement

Table 3. Comparison of γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$ with some other catalyst for the synthesis of **3c**.

Entry	Reagent	Time (min)	Yield (%)[a]	Ref.
1	PW$_{12}$	300	92	13
2	PW$_{12}$/PA	200	90	14
3	CsHPW	30	85	27
4	CH$_3$COONa/ U.S.	120	83	10
5	CH$_3$COOH/ U.S.	100	87	28
6	γ-Fe$_2$O$_3$@SiO$_2$-PW$_{12}$	100	90	This work

References

[1] R.H. Wiley, Ed.; Pyrazoles, Pyrazolines, Pyrazolidines, Indazoles and Condensed Rings; in the Chemistry of Heterocyclic Compounds; Weissberger A, Ed.; Interscience Publishers: New York, 1967; Vol. 22, p 180.

[2] K. Manna, Y.K. Agrawal. Bioorg. Med. Chem. Lett., 19 (2009) 2688-2692.

[3] M. Abid, A.R. Bhat, V. Athar, A. Azam, Eur. J. Med. Chem., 44 (2009) 417-425.

[4] Z.A. Kaplancikli, G. Turan-Zitouni, A. Özdemir, Ö. D. Can, P. Chevallet. Eur. J. Med. Chem., 44 (2009) 2606-2610.

[5] D. Havrylyuk, B. Zimenkovsky, O. Vasylenko, L. Zaprutko, R. Lesyk, Eur. J. Med. Chem., 44 (2009) 1396-1404.

[6] N. Gokhan-Kelekci, S. Koyunoğlu, S. Yabanoğlu, K. Yelekçi, Ö. Özgen, G. Uçar, K. Erol, E. Kendi, A. Yeşilada. Bioorg. Med. Chem., 17 (2009) 675-689.

[7] Barsoum F F, Hosni H M, Girgis A S. Bioorg Med Chem, , 14 (2006) 3929-3937.

[8] S.J. Ji, H.B. Shi. Dyes Pigments, 70 (2006) 246-250.

[9] X.Q. Wei, G. Yang, J.B. Cheng, Z.Y. Lu, M.G. Xie, Opt. Mater., 29 (2007) 936-940.

[10] J.-T. Li, X.-H. Zhang, Z. –P. Lin, Beilstein J. Org. Chem., 3 (2007) 13-16.

[11] A. Levai, ARKIVOC, No.ix (2005) 344-352.

[12] M. Kidwai, S. Kukreja, R. Thakur. Lett. Org. Chem., 3 (2006) 135-139.

[13] R. Fazaeli, H. Aliyan, M. Bordbar, E. Mohammadi, The Open Catal. J., 3 (2010) 79-82.

[14] R. Fazaeli, H. Aliyan, S. Mallakpour, Z. Rafiee, M. Bordbar. Chin. J. Catal. 32 (2011) 582-588.

[15] S. Safaee, I. Mohammadpour-Baltork, A.R. Khosropour, M. Moghadam, S. Tangestaninejad, V. Mirkhani, Adv. Synth. Catal., 345 (2012) 3095-3104.

[16] I. V. Kozhevnikov, I. V.;Sinnema, A.; R. J. J. Jansen, R. J. J.; Bekkum, H. Catal. Lett., 27 (1994) 187-197.

[17] G.D. Yadav, N. Kirthivasan, Appl. Catal. A: Gen., 154 (1997) 29-53.

[18] M. Misono, Chem. Commun. (2001) 1141-1442.

[19] I. Kozhevnikov, "Catalysts for Fine Chemical Synthesis, Catalysis by polyoxometalates", Vol 2. Wiley, NewYork.

[20] E. Rafiee, S. Eavani, F. KhajooeiNejad and M. Joshaghani, Tetrahedron, 66 (2010) 6858-6863.

[21] H. Zeng, H. Li and H. Shao, Ultrason. Sonochem., 16 (2009) 758-762.

[22] R. H. Wiley, C.H. Jarboe, F.N. Hayes, E. Hansbury, J.T. Nielsen, P.X. Callahan, M.C. Sellars. J. Org. Chem., 23 (1958) 732-738.

[23] E. Darezereshki, M. Ranjbar and F. Bakhtiari, J. Alloys Compd., 502 (2010) 257-260.

[24] E. Rafiee, S.Eavani, Green Chem., 13 (2011) 2116-2122.

[25] C. He, T. Sasaki, Y. Shimizu andN.Koshizaki, Appl. Surf. Sci., 254 (2008) 2196-2202.

[26] K. C. Barick, B. S. D. Ch. S. Varaprasad and D. Bahadur, J. Non-Cryst. Solids, 356 (2010) 153-159.

[27] R. Fazaeli,H. Aliyan, S. Tangestaninejad, E. Mohammadi, M. Bordbar, Chinese J. Catal., 33 (2012) 237-246.

[28] Z.P. Lin, J.-T. Lie., E. J. Chem., 9 (2012) 267-271.