

Application of Yttrium Iron Garnet as a Powerful and Recyclable Nanocatalyst for One-Pot Synthesis of Pyrano[2,3-*c*]pyrazole Derivatives under Solvent-Free Conditions

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Abstract—The application of yttrium iron garnet (YIG) superparamagnetic nanoparticles as a new recyclable and highly efficient heterogeneous magnetic catalyst for one-pot synthesis of pyrano[2,3-*c*]pyrazole derivatives under solvent-free conditions, as well as etherification and esterification reactions are described. The advantages of the proposed method include the lack of organic solvents, clean reaction, rapid removal of the catalyst, short reaction times, excellent yields, and recyclability of the catalyst.

Keywords: nanoparticle, yttrium iron garnet, pyrano[2,3-*c*]pyrazole, etherification, esterification, one-pot synthesis, sol-gel

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INTRODUCTION

Search for new catalysts with excellent activity, high selectivity, low toxicity, high surface area, high stability and, more important, allowing easy removal is among the main aims of chemical research and industry [1–3]. These properties are characteristic of magnetic nanoparticles (MNPs), among which ferrites MNPs are have by far been the most used type of MNPs. The application of ferrites MNPs in a wide range of sensors, imaging agents, storage media, adsorbents, microelectronics, and catalysts and catalyst supports in chemistry and biomedicine have been reported [4–9].

Garnets are interesting ferrites, and many studies have been devoted to their magnetic properties. Since its discovery in 1956, yttrium iron garnet (YIG) has attracted a lot of attention due to its applications in magneto-optical domains and microwave devices [10–12]. Despite of the great utility of ferrites in chemical synthesis, as well as higher scores of garnet than other ferrites, it has not yet been used as a catalyst in chemistry.

Recently, significant attention has been paid to nitrogenous heterocycles as the largest and important

group of natural active compounds. Among them polyfunctional heterocyclic compounds have emerged as the most important class of nitrogenous heterocycles in the field of organic, combinatorial and pharmacological chemistry because of their presence as efficient core structures in many biologically active compounds [13]. Pyrano[2,3-*c*]pyrazole derivatives, which belong to this class of heterocycles, exhibit a broad spectrum of biological activities, both natural and synthetic, and play a special role in the design of anticancer, anti HIV, antitumor, anti-inflammatory, analgesic, bronchodilator, antiviral, antipyretic, anti-fungal, antibacterial, antiprotozoal, and anticoagulant drugs [14–20].

In the present study we demonstrated the utility of YIG superparamagnetic nanoparticles as a catalyst for mild and efficient synthesis of pyrano[2,3-*c*]pyrazole derivatives. The YIG catalyst showed such advantages as simple work up, clean reaction, short reaction times, excellent yields, as well as easy removability and recyclability.

RESULTS AND DISCUSSION

The take nanoparticles discovered in other sciences and test their catalytic properties in chemistry allows

one to save time and money for the synthesis and identification of new materials. Yttrium iron garnet $\text{Y}_3\text{Fe}_5\text{O}_{12}$ (YIG) is an example of ferrimagnetic ceramics used in passive microwave devices. It contains Fe^{3+} and Y^{3+} ions distributed between different sites of the compound [21]. Nanoparticles of YIG were prepared according to the reported procedure [22] with a minor modification. The surface-to-volume ratios of nanoparticles are very high and crucial in their catalytic effect in organic synthesis, and, therefore, the increase of this ratio with decreasing particle size enhances the catalytic activity of the nanoparticles.

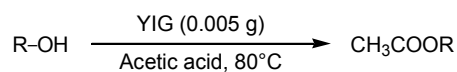
Superparamagnetic YIG nanoparticles of about 40–50 nm were prepared using the sol–gel method, which

is an effective synthetic tool with excellent advantages widely accepted in industry and organic synthesis (see Supplementary materials). The catalytic performance of YIG nanoparticles was first tested in simple etherification (Table 1) and esterification (Table 2). Reactions and the catalyst showed good activity in both reactions. After successful testing with excellent results, YIG nanoparticles was used for the one-pot multicomponent synthesis of pyrano[2,3-*c*]pyrazole derivatives (Table 3).

In summary, in the present study, superparamagnetic nanoparticles of YIG were used as a green, an efficient, and an easy-to-handle catalyst for etherification and esterification reactions and synthesis of pyrano[2,3-*c*]pyrazole derivatives. This method

Table 1. Solvent-free etherification of alcohols in the presence of YIG nanoparticles

$2\text{R-OH} \xrightarrow[\text{Solvent-free, } 80^\circ\text{C}]{\text{YIG (0.005 g)}} \text{ROR}$				
Entry no.	R-OH	Product	Time, min	Yield, %
1		ROR	15	91
2		ROR	15	93
3		ROR	15	93
4		ROR	15	91
5		ROR	15	95
6		ROR	15	93
7		ROR	15	91
8		ROR	15	87
9		ROR	20	87
10		ROR	20	89

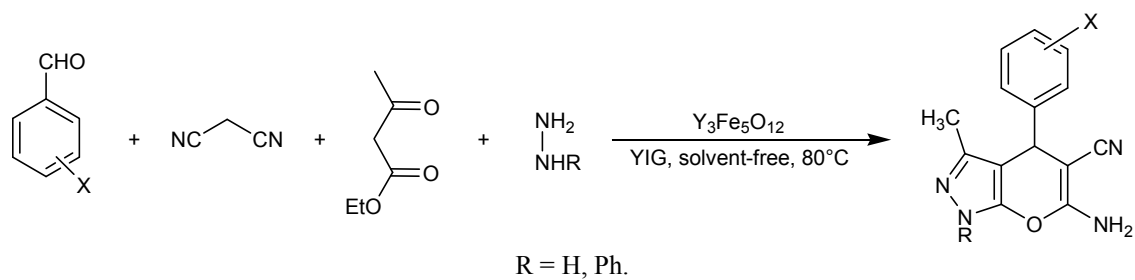
Table 2. Solvent-free acetylation of alcohols with acetic acid in the presence of YIG nanoparticles

Entry no.	R-OH	Product	Time, min	Yield, %
1	CH ₃ CH ₂ OH	CH ₃ COOR	15	93
2		CH ₃ COOR	15	94
3		CH ₃ COOR	15	94
4		CH ₃ COOR	15	93
5		CH ₃ COOR	15	94
6		CH ₃ COOR	20	94
7		CH ₃ COOR	20	91
8		CH ₃ COOR	20	93
9		CH ₃ COOR	20	93
10		CH ₃ COOR	20	91
11		CH ₃ COOR	20	89
12		CH ₃ COOR	20	87

offers some advantages, including high yields and short reaction times. The catalyst could be reused more than eight reaction cycles with significant loss in catalytic activity (Fig. 1, for the first cycle 96% and for the Eighth cycle 91% yield). The proposed interesting concept of using garnet MNPs as a catalyst can be extended to other organic syntheses.

EXPERIMENTAL

All solvents and reagents purchased from Sigma-Aldrich and Merck and were of high-grade quality used as received. Products were separated, purified by different chromatographic techniques, and identified by comparing their IR and NMR

Table 3. One-pot three-component synthesis of pyrano[2,3-*c*]pyrazole derivatives in the presence of YIG nanoparticles

Entry no.	Aldehyde	R	Product	Time, min	Yield, %
1		H		20	94
2		H		20	91
3		H		20	90
4		H		20	90
5		H		20	89

Table 3. (Contd.)

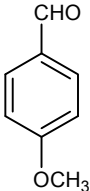
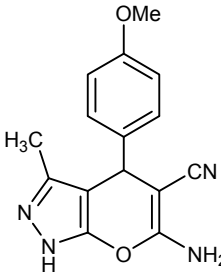
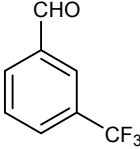
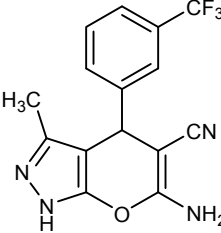
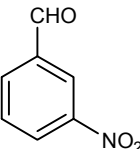
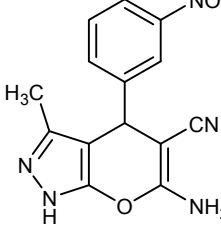
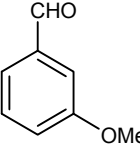
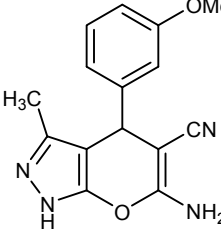
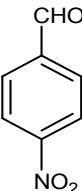
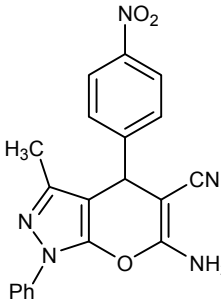
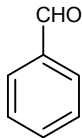
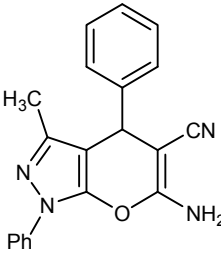
Entry no.	Aldehyde	R	Product	Time, min	Yield, %
6		H		20	92
7		H		20	89
8		H		20	91
9		H		20	90
10		PH		20	95
11		PH		20	90

Table 3. (Contd.)

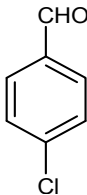
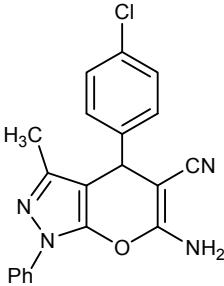
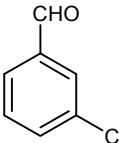
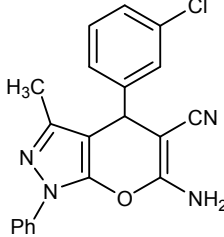
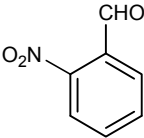
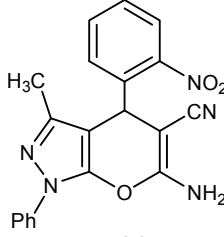
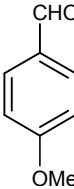
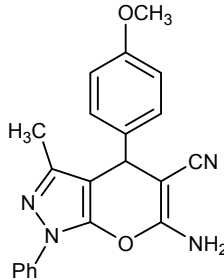
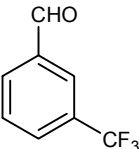
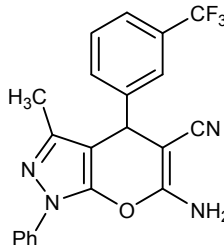
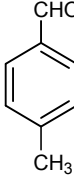
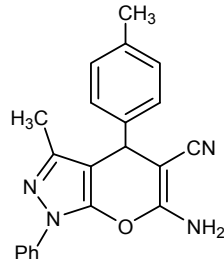
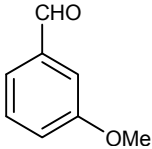
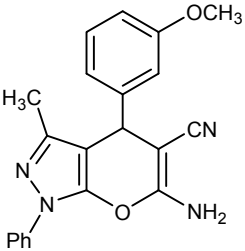
Entry no.	Aldehyde	R	Product	Time, min	Yield, %
12		PH		20	90
13		PH		20	92
14		PH		30	90
15		PH		20	92
16		PH		20	93
17		PH		20	94

Table 3. (Contd.)

Entry no.	Aldehyde	R	Product	Time, min	Yield, %
18		PH		20	89

spectra and melting points with respective characteristics of authentic samples. Yttrium iron garnet was prepared according to [24] with minor modifications.

The ^1H and ^{13}C NMR spectra were measured on a Bruker DPX-400 AVANCE spectrometer in CDCl_3 against internal TMS. The IR spectra were obtained on a Perkin–Elmer LXI85256 spectrometer. The melting points were determined on an electrothermal capillary melting point apparatus and are uncorrected. The reaction progress was monitored by TLC (on silica gel polygram SILG/UV 254 plates) given in Supplementary materials through scanning electron microscopy, transmission electron microscopy (TEM), thermogravimetric analysis (TGA).

Synthesis of nano yttrium iron garnets $\text{Y}_3\text{Fe}_5\text{O}_{12}$. Weighed amounts of $\text{Y}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ (1.56 g) and

$\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ (2.74 g) were dissolved in deionized water (50 mL). After stirring at room temperature (1 h), citric acid (6.83 g) was added to the solution, and it was refluxed at 80°C for 60 min until to allow formation of a gel which was then dried at 115°C for 24 h. The dry powder was ground and annealed at 1000°C for 4 h (Fig. 2). The product was characterized by XRD, FT-IR spectroscopy, SEM, TEM and TGA. (For detailed information, see Supplementary materials).

Typical procedure for etherification of alcohols in the presence of YIG nanoparticles. 2 mmol of alcohol and 0.005 g of catalyst was heated at 80°C . The progress of the reactions was monitored by TLC (acetone–*n*-hexane, 1 : 2). After completion of the reaction, the catalyst was easily removed from the product by turning off the stirrer without using any external magnet. The product was removed and dried

Table 4. Comparison of different catalysts in the synthesis of pyrano[2,3-*c*]pyrazole

Entry no.	Catalyst	Time, min	Yield, %	Reference
1	SPPyNs ^a	30–60	50–92	[25]
2	DBSA ^b	180	82–94	[26]
3	Palladium nanoparticles	4–43	85–90	[27]
4	PVPy ^c	18–65	89–92	[28]
5	SB-DABCO ^d	25–60	93–97	[29]
6	NMPyTS ^e	30–60	79–82	[30]
7	YIG nanoparticles	15–20	89–95	This work

^a Sulfonated polypyrrolenanospheres.

^b *p*-Dodecylbenzenesulfonic acid.

^c Poly(4-vinylpyridine).

^d Silica bonded *n*-propyl-4-aza-1-azoniabicyclo[2.2.2]octane chloride.

^e *N*-Methyl pyridinium tosylate.

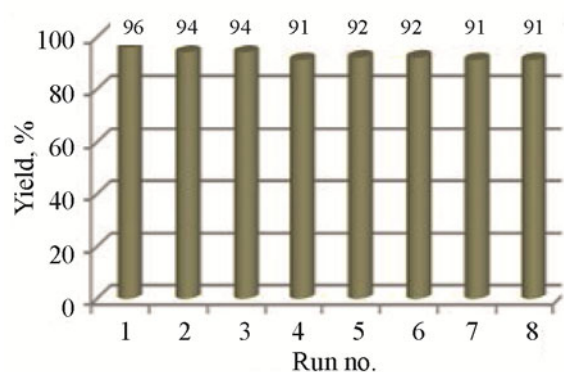


Fig. 1. Recyclability of YIG in the synthesis of pyrano[2,3-*c*]pyrazole derivatives under solvent- free conditions.

under vacuum. For the reaction times and the structures and yields of the products, see Table 1.

Typical procedure for acetylation of alcohols with acetic acid in the presence of YIG nanoparticles. Mixture of 0.005 g and glacial acetic acid was placed in a 50-mL round bottom flask, and was stirred for 5 min. Then, alcohol (1 mmol) was added to the solution, and reaction solution was stirred under reflux condition for specified time. The progress of reaction was monitored by TLC (acetone–*n*-hexane, 1 : 2). After completion of the reaction, catalyst was easily removed by shutting down the stirrer without using any external magnet. The product was purified by recrystallization in hot ethanol. For the reaction times and the structures and yields of the products, see Table 2.

Typical procedure used for preparation of pyrano[2,3-*c*]pyrazole derivatives. A mixture containing ethyl acetoacetate (1 mmol), hydrazine/phenylhydrazine (1 mmol), aromatic aldehyde (1 mmol), malononitrile (1 mmol), and nanopowders of yttrium iron garnet (0.005 g) was heated at 80°C under well-mixed conditions for appropriate time. Completion of the reaction was indicated by TLC (acetone–*n*-hexane, 1 : 2). After completion of the reaction, the stirrer was turned off, and the entire catalyst was readily collected by the internal magnet, and was washed by 10 mL of water–ethanol solution (1 : 1), and then was dried in air for further use. Insoluble crude product was dissolved in hot ethanol, and the product was purified by recrystallization in ethanol to afford a pure product. For the reaction times and the structures and yields of the products, see Table 3.

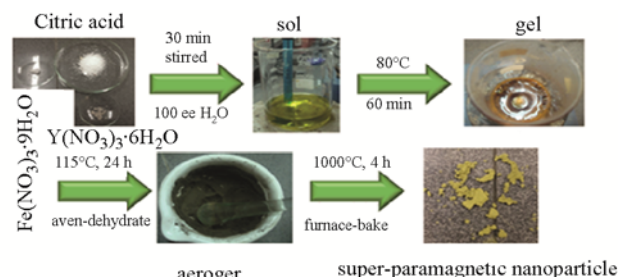


Fig. 2. Preparation of nano yttrium iron garnets $\text{Y}_3\text{Fe}_5\text{O}_{12}$.

SUPPLEMENTARY MATERIALS

Supplementary materials are available for this article at <https://doi.org/10.1134/S1070428019110186> and are accessible for authorized users.

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CONFLICT OF INTEREST

The authors declare no conflict of interest

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