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ORIGINAL PAPER

γ-Aminobutyric acid hydrochloride supported on superparamagnetic γ-Fe_2O_3@SiO_2 as a novel heterogeneous nanocatalyst for the synthesis of 2-amino-5-alkylidene-thiazol-4-one derivatives

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Abstract

γ-Aminobutyric acid hydrochloride immobilized on superparamagnetic γ-Fe_2O_3@SiO_2 nanoparticles as a novel heterogeneous nanocatalyst was prepared for the first times. It was characterized by several techniques such as XRD, FT-IR, VSM, FE-SEM, EDS, and TGA analysis. The heterogeneous nanocatalyst was used for a convenient, mild, and one-pot efficient three-component preparation of 2-amino-5-alkylidene-thiazol-4-one derivatives under green conditions at room temperature. The main advantage of the method is easily recovery of the stable nanocatalyst by an external magnet from the reaction mixture.

Keyword Nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] · Superparamagnetic nanocatalyst · 2-Amino-5-alkylidene-thiazol-4-ones · Three-component reaction, · Green reaction

Introduction

Organic reactions using heterogeneous catalysts are extremely important for the development of the concept of "Sustainable Chemistry" [1]. Nano-sized metal particles, a new branch of material research, has attracted considerable attention because of their potential applications in areas such as biotechnology/biomedicine [2], magnetic resonance imaging (MRI) [3], versatile catalysts for green and sustainable organic synthesis, magnetic data storage, and nanocomposites [4]. Nano superparamagnetic transition metal oxides such as iron are one of the most adjustable systems which have applied in medical, industrial and biological systems in addition to their important roles in catalysis and organic synthesis [5–7]. Thus, studies of new types of organometallic compounds grafting of organocatalysts on the superparamagnetic iron oxide nanoparticles were attracting the consideration of researchers in organic chemistry [8].

Acidic and basic organic compounds have achieved a great attention in the fields of organic synthesis [9]. In spite of their widespread use in organic reactions, their practical applications have been restricted by some difficulties in its recovery which lead to economical and environmental problems [10]. The immobilization of acidic and basic organic compounds onto solid materials can be overcome by problems accompanied in the use of them [11]. Covalent anchoring of acidic and basic organic compounds onto a heterogeneous surface is an attractive approach to its easy recovery and reuse in chemical processes [12]. Magnetic nanoparticles (MNPs) have been used as a novel type of support for organocatalysts as they offer benefits in clean and sustainable chemistry due to their excellent chemical stability, good accessibility, reusability, simple preparation and modification, large surface area, easy separation with an external magnet, and relatively low toxicity [13, 14]. These attractive features have made the MNPs a promising alternative type of catalyst supports.

Multi-component reactions (MCRs) have been developed in preparation of complex organic molecules from simple and available starting materials without the isolation of any intermediates. MCRs make efficient pathway in modern sustainable and "green" synthetic organic compounds [15].

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2-Amino-5-alkylidene-thiazol-4-one derivatives have been reported in drug discovery, and showed the biological, antiviral, antimicrobial, cardiotonic, anti-inflammatory, inhibitor and anticancer activities (Fig. 1) [16–18].

In continuation of our research on the supported organocatalysts on superparamagnetic materials and their applications in organic synthesis [19], herein, we have assisted three-component one-pot synthesis of 2-amino-5-alkylidene-thiazol-4-one derivatives using a novel heterogeneous nanocatalyst, nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid.HCl)], in water–ethanol mixture as a green medium solvent under mild conditions at room temperature (Scheme 1).

Results and discussion

New nano-γ-Fe_2O_3@$[CH_2]_3$-(γ-aminobutyric acid.HCl)] as a superparamagnetic nanocatalyst was synthesized based on the following procedure (Scheme 2). First, superparamagnetic Fe_3O_4 nanoparticles were facilely prepared by a chemical co-precipitating method. Second, Fe_3O_4 converted to γ-Fe_2O_3 at 300 °C for 3 h and in following γ-Fe_2O_3 was coated with tetraethyl orthosilicate (TEOS). Then, γ-Fe_2O_3@SiO_2 coated by (3-chloropropyl)trimethoxysilane as chloro-functionalized γ-Fe_2O_3@SiO_2. Finally, the reaction of γ-aminobutyric acid with chloro-functionalized γ-Fe_2O_3@SiO_2 formed nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid.HCl)] as a superparamagnetic nanocatalyst.

The magnetic nanocatalyst was characterized using different techniques such as XRD, SEM, EDS, VSM, TGA and FT-IR. The XRD pattern of γ-Fe_2O_3 and nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid.HCl)] had six characteristic peaks which have a good accordance with the cubic structure of magnetite (γ-Fe_2O_3) (JCPDS file No. 04-0755). The positions of all the peaks indicated retention of the crystalline structure during functionalization of the MNPs, and the grafting process did not change phase of the γ-Fe_2O_3 nanoparticles. The XRD pattern of γ-Fe_2O_3 and nano-γ-Fe_2O_3@$[CH_2]_3$-(γ-aminobutyric acid.HCl)] showed that SiO_2 and organocatalyst formed amorphous phase which their patterns showed only pattern of crystalline γ-Fe_2O_3 nanoparticles (Fig. 2).

Figure 3 represents the FE-SEM image of nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid.HCl)] that shows spherical morphology and average size 16 nm of nanoparticles using histogram curve.

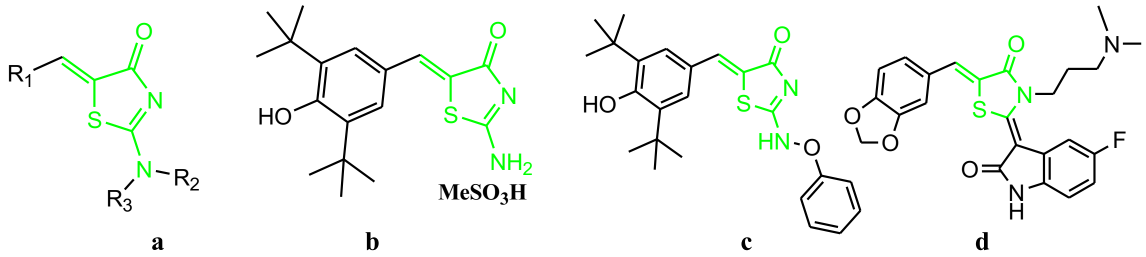
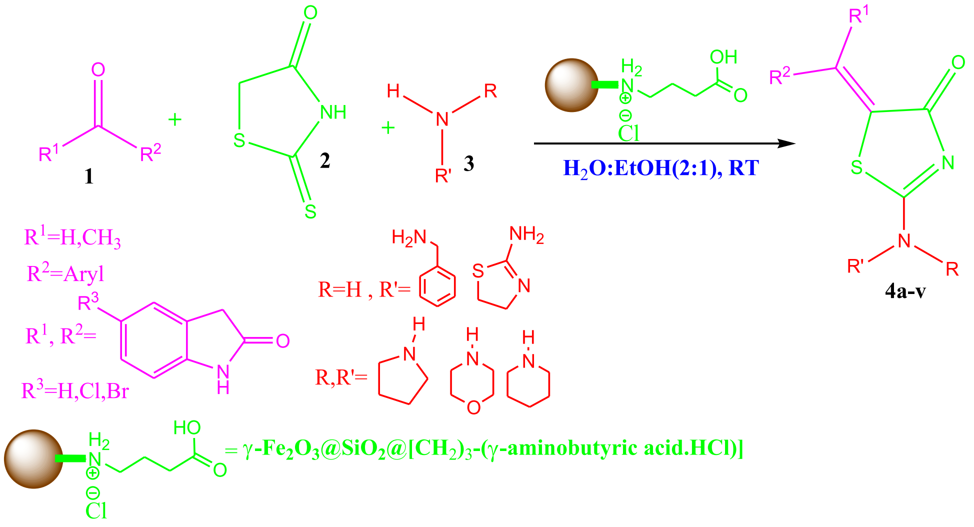
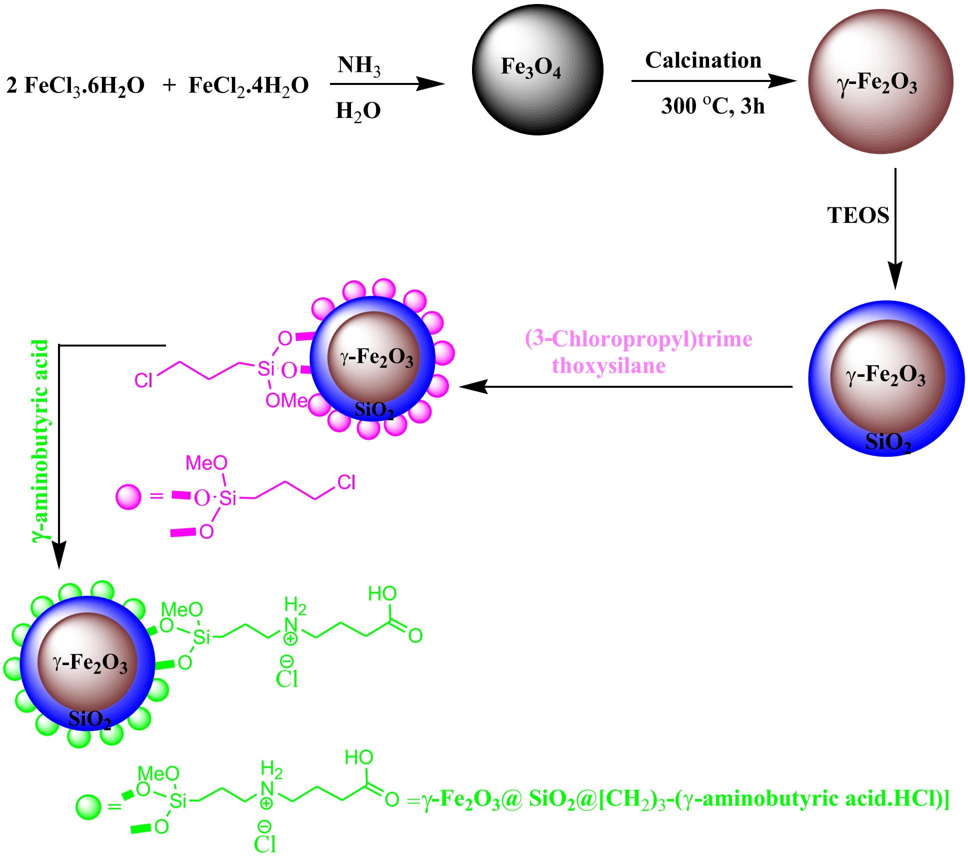


Fig. 1 Structure of some molecules with biological activity: 2-amino-5-alkylidene-thiazol-4-ones (**a**–**c**) and isatin–thiazolidinone hybrid (**d**)

Scheme 1 Synthesis of 2-amino-5-alkylidene-thiazol-4-one derivatives in the presence of nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid.HCl)] as a superparamagnetic nanocatalyst



Scheme 2 Synthesis of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] as a new superparamagnetic nanocatalyst



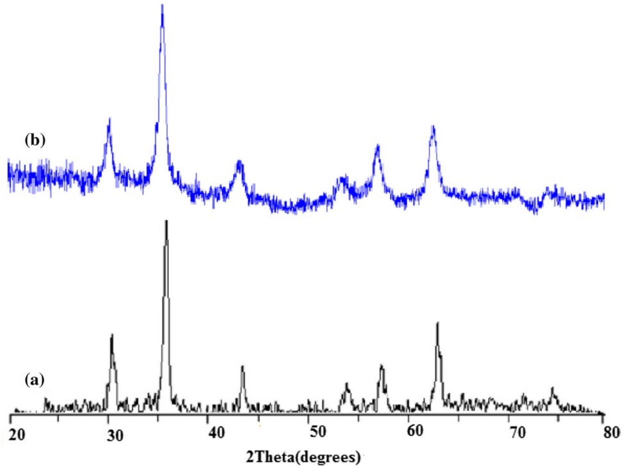


Fig. 2 XRD pattern of **a** γ-Fe_2O_3, **b** nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)]

The components of the nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] were analyzed using EDS. The EDS spectrum in Fig. 4 implicates the presence of atoms Fe, O, Si, C, Cl and N in the catalyst which confirm the structure of the organocatalysts supported on γ-Fe_2O_3@SiO_2.

The VSM diagram shows the magnetic properties of synthesis catalyst (Fig. 5). The hysteresis loops of organocatalysts immobilized on γ-Fe_2O_3@SiO_2 were measured. Magnetization (emu g^{-1}) as a function of applied field (Oe) is depicted in Fig. 5 with the confined field from − 10,000 to 10,000 Oe. Superparamagnetic behavior of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] nanocrystals illustrates small particle size. As it can be observed, saturation magnetization value of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] is 60 amu g^{-1}.

The thermal stability of the nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] was investigated by TGA analysis (Fig. 6). Small weight loss occurs below 180 °C, is due to physically adsorbed solvent. There is exothermic peak accompanied with a mass loss of 6.5% in the temperature range of 180–480 °C in the TGA curve of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)]. These peaks were mainly attributed to the decomposition of organic groups grafted to the γ-Fe_2O_3 surface, the peak higher than 500 °C most probably corresponds to a phase transition in which the amorphous phase is converted to a crystalline phase.

The characterization of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] was confirmed by FT-IR spectrum. The C–H stretching vibrations peak appear at

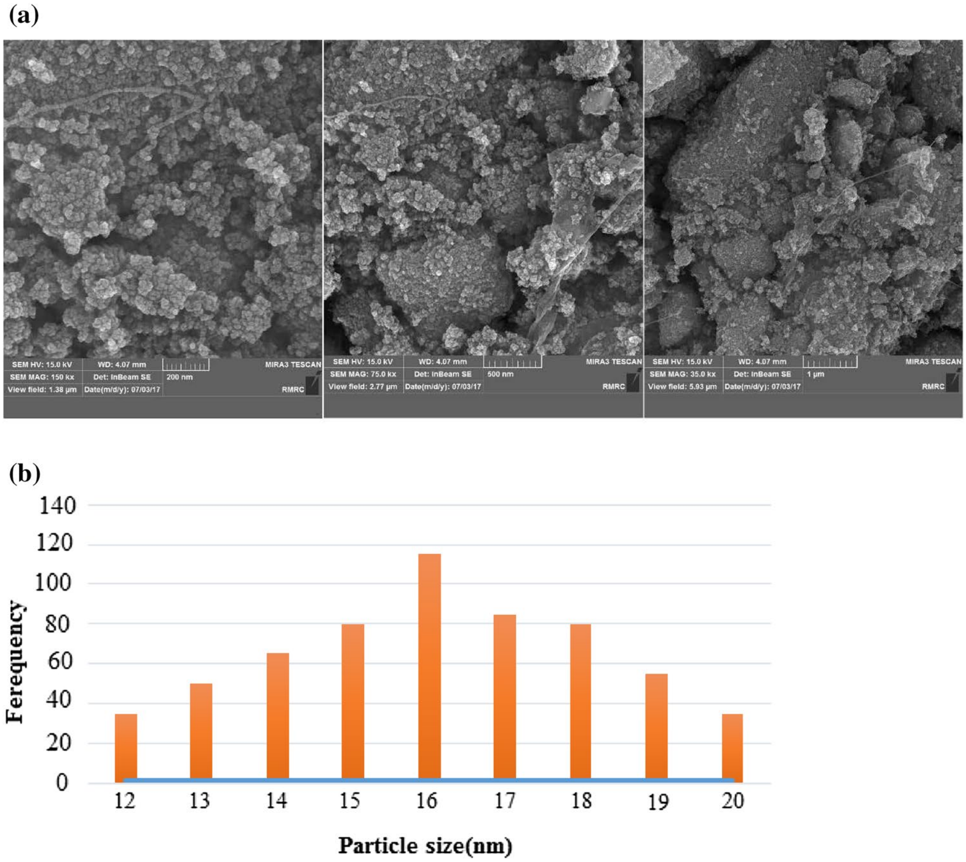


Fig. 3 **a** FE-SEM image of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)]; **b** particle size distribution histogram curve of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)]

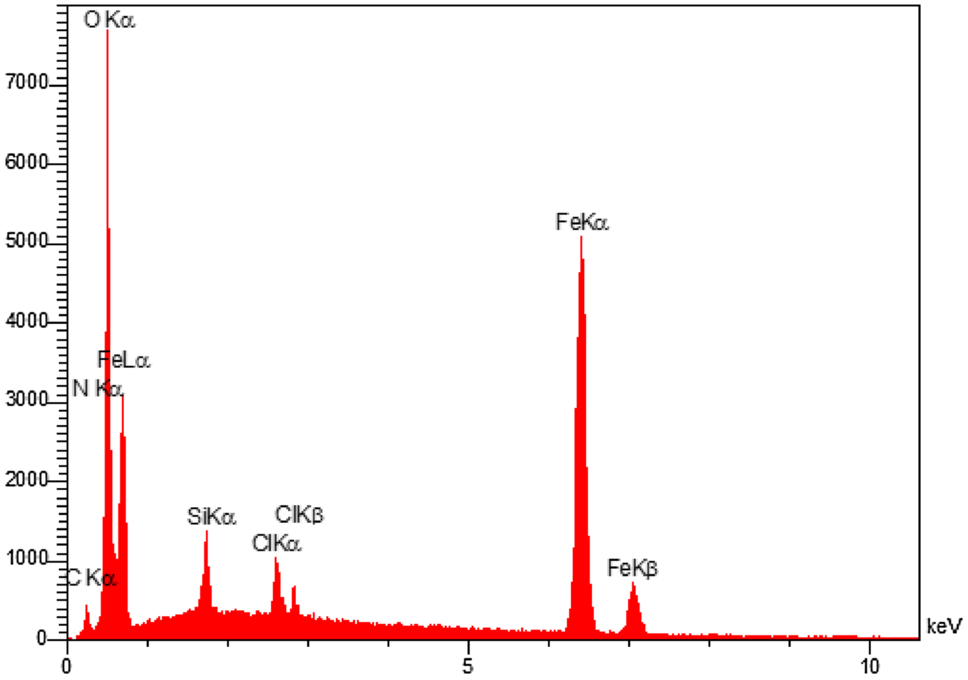


Fig. 4 EDS spectrum of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)]

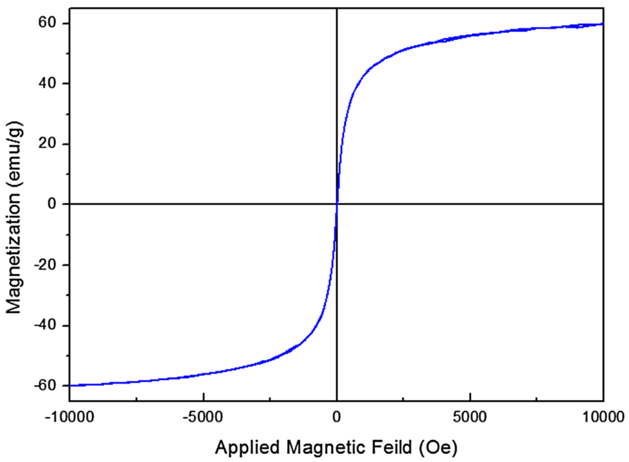


Fig. 5 VSM diagrams of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)]

2930 cm^{-1}. The Fe–O stretching vibration was observed 550–650 $cm^{-1}$and stretching mode of C=O showed a peak at about 1620 cm^{-1}. The O–H stretching bands peak appear at 3405 cm^{-1} (Fig. 7).

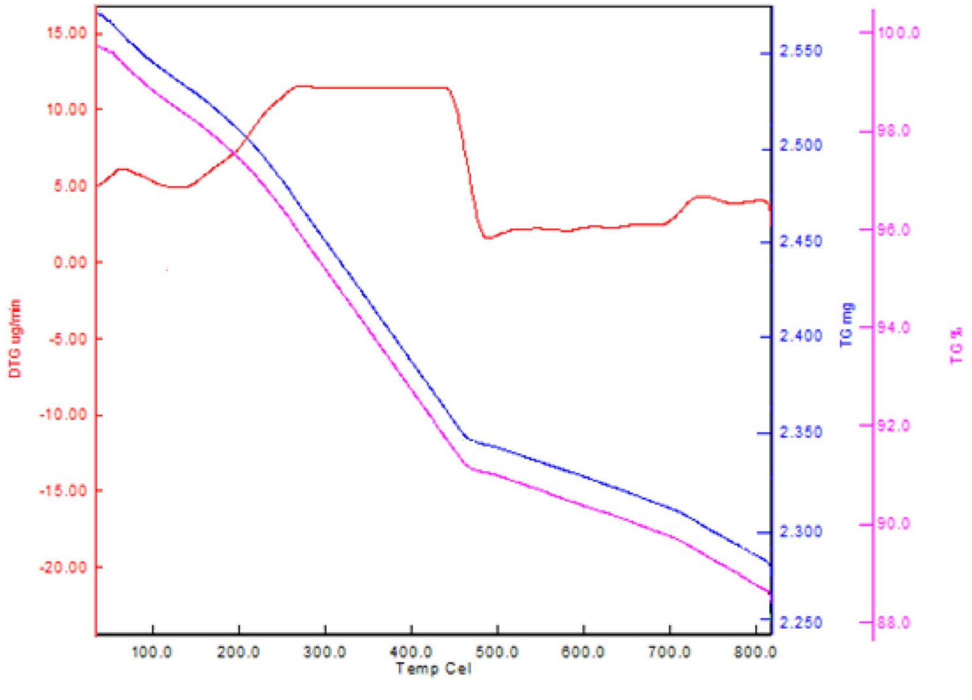
Optimization of the reaction conditions

To evaluate the activity of the nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] as nanocatalyst, at first, the one-pot and three-component reaction of rodanine (1 mmol), 4-chlorobenzaldehyde (1 mmol), and 2-amino-2-thiazoline (1 mmol) (Scheme 3) was chosen as a model reaction to optimize the reaction conditions such as molar ratio of the catalyst, temperature and solvents (Table 1,2, 3).

To show the unique catalytic behavior of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] as nanocatalyst and to compare its activity with other catalysts, this reaction was performed in the presence of catalytic amount of Fe_3O_4 NMPs, *p*-TSA, AcOH, DBU, sulfamic acid, MgO–NPs, γ-aminobutyric acid, Et_3N, and catalyst free in different solvents. The results are summarized in Table 1. With regard to the results in Table 1, It was shown that the activity of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] > Fe_3O_4 NMPs > $FeCl_3.6H_2O$. Excellent yield of the product (85%) in minimum time period (60 min) was obtained using MNPs-organocatalyst as catalyst (Table 1, Entry 6). Also, we examined the reaction in the absence of any catalyst, and in the presence of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] as catalyst in H_2O:EtOH(1:1) (3 mL) as solvent (Table 1, Entries 2, 6). It was found that the best yield of the product was obtained at room temperature in the presence of 5 mg of MNPs-organocatalyst. A similar reaction in the presence of γ-aminobutyric acid as a non-supported on MNPs gave the desired product in moderate yield (55%). The results showed that the catalytic efficiency of γ-aminobutyric acid was increased by immobilization onto γ-Fe_2O_3@SiO_2 (Table 1, Entry 6).

Taking into account the data of the Table 1, comparing the catalyst activity of MNPs-organocatalyst with *p*-toluene-sulfonic acid, sulfamic acid, trimethylamine, acetic acid, magnesium oxide nanoparticles, and 1,8-diazabicyclo[5.4.0]undec-7-ene, MNPs-organocatalyst as catalyst has the advantages of the low ratio of the catalyst in the

Fig. 6 Thermogravimetric analysis of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)]



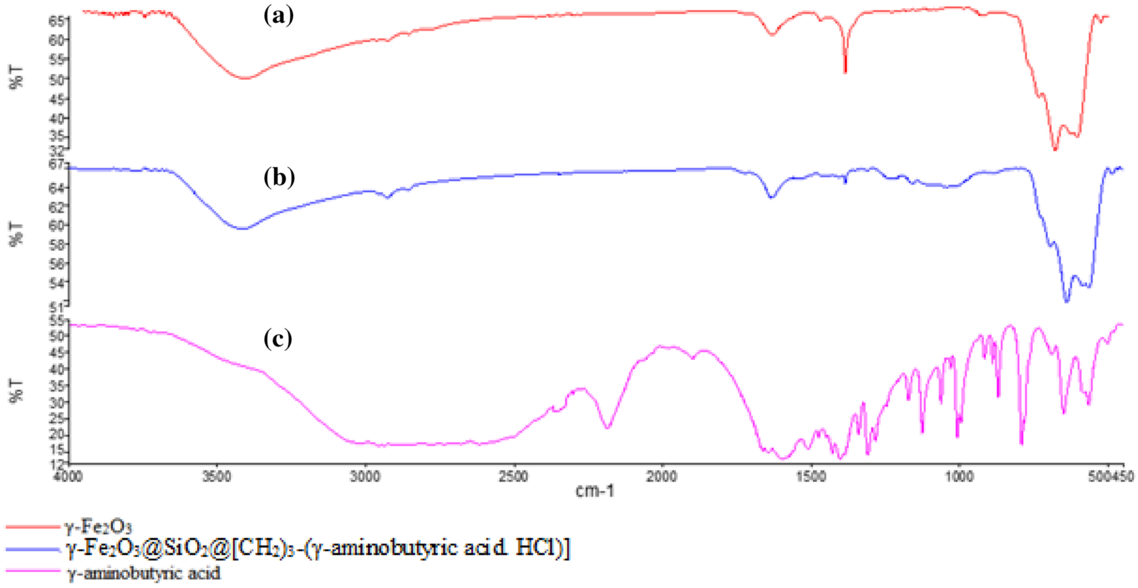
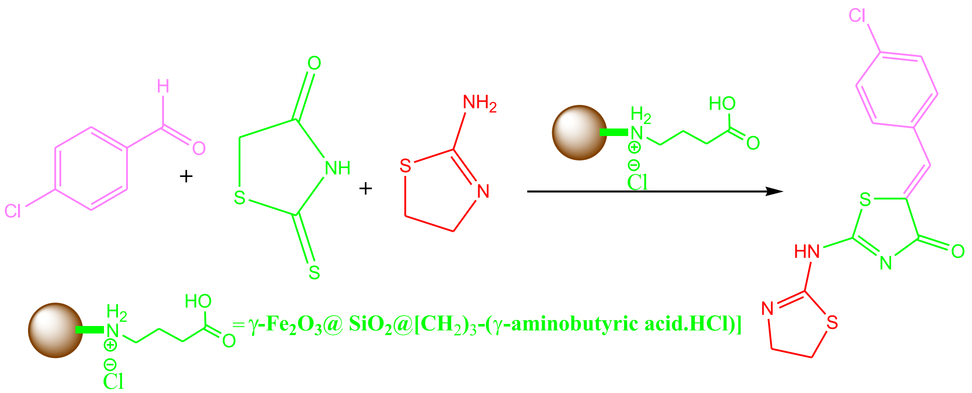


Fig. 7 FT-IR spectra: **a** γ-Fe_2O_3 and **b** nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)], **c** γ-aminobutyric acid

Scheme 3 Synthesis of 5-(4-chloro-benzylidene)-4′,5′-dihydro-[2,2′]bithiazolyl-4-one (selected reaction model)



synthesis of 5-(4-chloro-benzylidene)-4′,5′-dihydro-[2, 2′] bithiazolyl-4-one with good yields, low temperature, and the reusability of catalyst.

In terms of choosing the best solvent for the reaction of rodanine (1 mmol), 4-chlorobenzaldehyde (1 mmol), and 2-amino-2-thiazoline (1 mmol) (Scheme 3) to afford 4a, different solvents were studied in the presence of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] (Table 2). Comparing the reaction times and yields of products in different solvents such as H_2O, EtOH, H_2O:EtOH (1:1), H_2O:EtOH(1:2), H_2O:EtOH(2:1), THF, CH_3CN, CH_2Cl_2, and solvent-free system, the best result was obtained after 60 min in H_2O:EtOH(2:1) conditions by taking a 1:1:1 molar ratio mixture of rodanine, 4-chlorobenzaldehyde, and 2-amino-2-thiazoline .

The important of performance of the catalyst in H_2O:EtOH (2:1) relative to the results was obtained in H_2O, EtOH, H_2O:EtOH(1:1) and H_2O:EtOH(1:2) (Table 2, Entries 1, 6, 7, 9), wherein the reaction completed in 60 min with excellent yield of the product (92%) in H_2O:EtOH(2:1) (Table 2, Entry 10).

The effect of amount of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] was investigated for the synthesis of 5-(4-chloro-benzylidene)-4′,5′-dihydro-[2, 2′] bithiazolyl-4-one. Varying amount of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] was used from 2 to 7 mg in H_2O:EtOH(2:1) (3 mL) as solvent (Table 3). The optimum amount of catalyst for maximum conversion was found to be 5 mg (Table 3, Entry 4). Increasing the amount of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] showed no effect in the product yield (Table 3, Entry 5).

According to optimal considered conditions in this methodology, 2-amino-5-alkylidene-thiazol-4-one derivatives were synthesized and results are shown in Table 4.

According to the literature [16–18], the proposed mechanism for the formation of the product is shown

Table 1 Preparation of 5-(4-chloro-benzylidene)-4′,5′-dihydro-[2, 2′] bithiazolyl-4-one in the presence of nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid.HCl)], Fe_3O_4 NMPs, *p*-TSA, AcOH, DBU, sulfamic acid, Et_3N, γ-aminobutyric acid, MgO–NPs, $FeCl_3.6H_2O$, and catalyst-free in different solvents

Entry	Catalyst	Conditions	Time	Yield (%)[a,b]	Cite to literature
1	–	–	6 h	0	–
2	–	H_2O:EtOH(1:1) (3 mL) (RT)	5 h	25	–
3	*p*-TSA (30 mol%)	H_2O:EtOH(1:1) (3 mL) (RT)	2 h	61	–
4	AcOH (30 mol%)	H_2O:EtOH(1:1) (3 mL) (RT)	2 h	55	–
5	DBU (30 mol%)	H_2O:EtOH(1:1) (3 mL) (RT)	2 h	35	–
6	Nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid.HCl)] (5 mg)	Water:EtOH(1:1) (RT)	60 min	85	–
7	Et_3N (50 mol%)	H_2O:EtOH(1:1) (3 mL) (RT)	100 min	35	–
8	Nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid.HCl)] (5 mg)	Solvent free (RT)	2 h	45	–
9	Sulfamic acid (25 mol%)	H_2O:EtOH(1:1) (3 mL) (RT)	90 min	65	–
10	MgO–NPs (0.3 mol%)	Water (RT)	120 min	82	[16]
11	γ-Aminobutyric acid (25 mol%)	H_2O:EtOH(1:1) (3 mL) (RT)	2 h	55	-
12	$FeCl_3.6H_2O$	H_2O:EtOH(1:1) (3 mL) (RT)	2 h	55	-
13	Fe_3O_4 NMPs	H_2O:EtOH(1:1) (3 mL) (RT)	2 h	65	-

Table 2 Preparation of 5-(4-chloro-benzylidene)-4′,5′-dihydro-[2, 2′] bithiazolyl-4-one in the presence of nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid.HCl)] (5 mg) in different solvents

Entry	Solvent	Time (min)	Temperature (°C)	Yield (%)[a,b]
1	EtOH (3 mL)	90	RT	70
2	CH_3CN (3 mL)	150	RT	45
3	CH_2Cl_2 (3 mL)	150	RT	35
4	THF (3 mL)	150	RT	30
5	Solvent free	120	RT	45
6	H_2O (3 mL)	70	RT	80
7	H_2O:EtOH(1:1) (3 mL)	60	RT	85
9	H_2O:EtOH(1:2) (3 mL)	70	RT	75
10	H_2O:EtOH(2:1) (3 mL)	60	RT	92

[a] Reaction conditions: rodanine(1 mmol), 4-chlorobenzaldehyde (1 mmol), and 2-amino-2-thiazoline (1 mmol) in different solvent with nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid.HCl)] as catalyst

[b] Yield refer to isolated pure products

Table 3 Optimization conditions of the amount of the catalyst for the preparation of 5-(4-chloro-benzylidene)-4′,5′-dihydro-[2, 2′] bithiazolyl-4-one

Entry	Catalyst (mg)	Time (min)	Yield (%)[a,b]
1	2	90	75
2	3	85	82
3	4	70	87
4	5	60	92
5	7	50	92

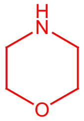
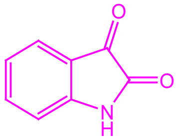
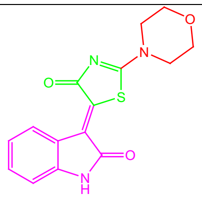
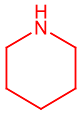
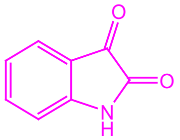
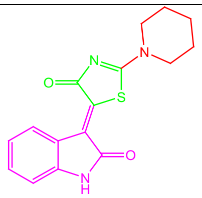
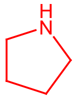
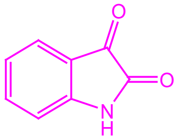
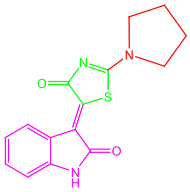
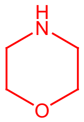
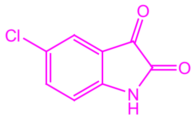
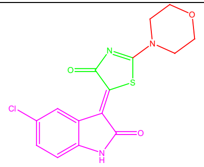
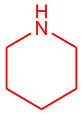
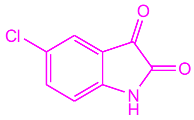
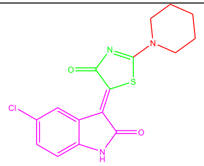
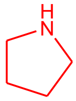
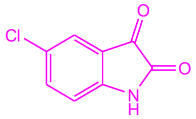
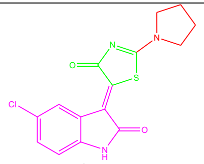
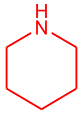
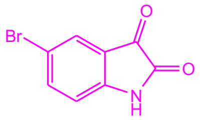
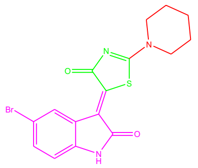
[a] Reaction conditions: rodanine(1 mmol), 4-chlorobenzaldehyde (1 mmol), and 2-amino-2-thiazoline(1 mmol) in water:ethanol (2:1) (3 mL) as a green medium solvent

[b] Yield refer to isolated pure products

in Scheme 4. At Route 1, first, intermediate (A) was formed through displacement of the thiocarbonyl sulfur (2) with primary or secondary amines (3) in the presence of MNPs-organocatalyst, in the following, intermediate (B) was obtained, then, the condensation reaction of (B) with isatins to produce (4a–h). At Route 2, intermediate (E) was formed through condensation between rhodamine 2 and molecule 1(aldehyde or ketone), and remove water of (E) to produce (F), next, product (4i–v) was obtained from through displacement of the thiocarbonyl sulfur (F) with primary or secondary amines (3).

The recyclability of nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid.HCl)] was examined in the one-pot three-component synthesis of 2-amino-5-alkylidene-thiazol-4-one derivatives under optimized conditions. After completion of reaction, the solvent was separated by filtration, and ethanol was added to the reaction mixture and heated to separate nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid.HCl)] by an external magnet. The catalyst was washed with ethanol for three times and dried. As it was shown in Fig. 8, even after five runs, catalytic activity and product yield have no significant loss. Thus, this catalyst can endure reaction conditions and remain stable.

Table 4 Synthesis of 2-amino-5-alkylidene-thiazol-4-one derivatives by nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] (5 mg) nanoparticles at room temperature in water: ethanol (2:1) (3 mL) as solvent

Entry	amine		product	Time(min)	Yield (%)^{a,b}	Observed M.p (°C)	Lit. M.p (°C) , Ref
1			 4a	60	90	>300	368-370 [16]
2			 4b	50	90	>300	345-347 [16]
3			 4c	35	89	250-253	250-252 [16]
4			 4d	55	92	>300	350-352 [16]
5			 4e	60	92	>300	346-347 [16]
6			 4f	45	89	>300	347-349 [16]
7			 4g	60	85	>300	346-348 [16]

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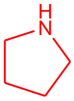
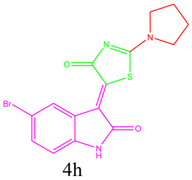
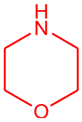
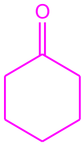
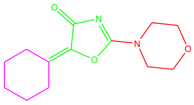
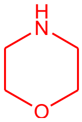
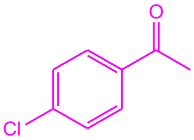
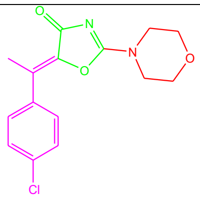
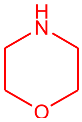
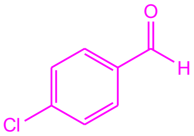
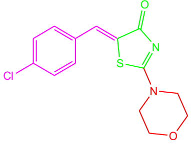
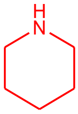
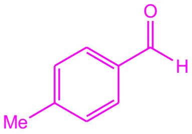
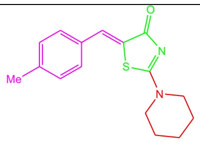
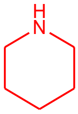
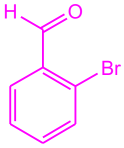
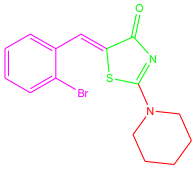
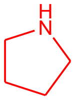
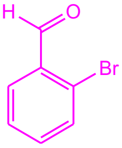
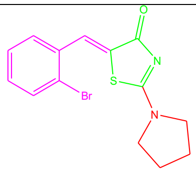
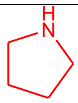
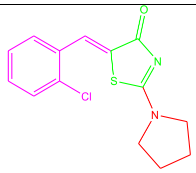
8			 4h	45	85	>300	359-361 [16]
9			 4i	120	80	177-179	178-180 [17]
10			 4j	150	70	227-230	228-230 [17]
11			 4k	55	95	235-238	236-238 [18]
12			 4l	55	95	153-155	152-154 [18]
13			 4m	55	93	163-165	162-164 [18]
14			 4n	60	90	210-213	210-212 [18]
15			 4o	65	90	236-239	236-238 [18]

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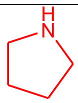
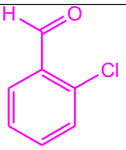
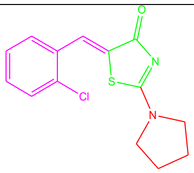
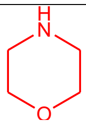
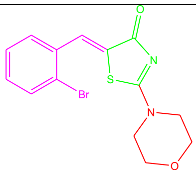
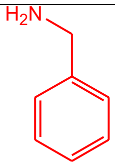
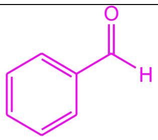
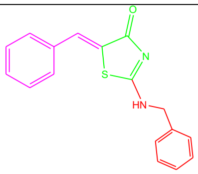
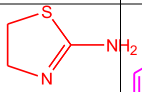
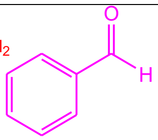
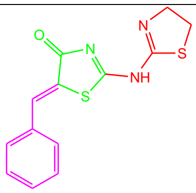
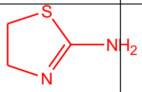
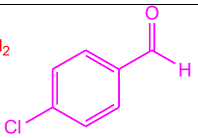
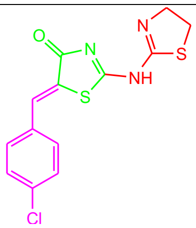
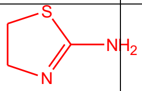
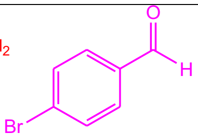
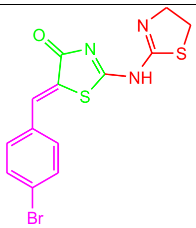
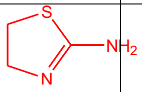
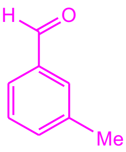
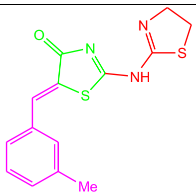
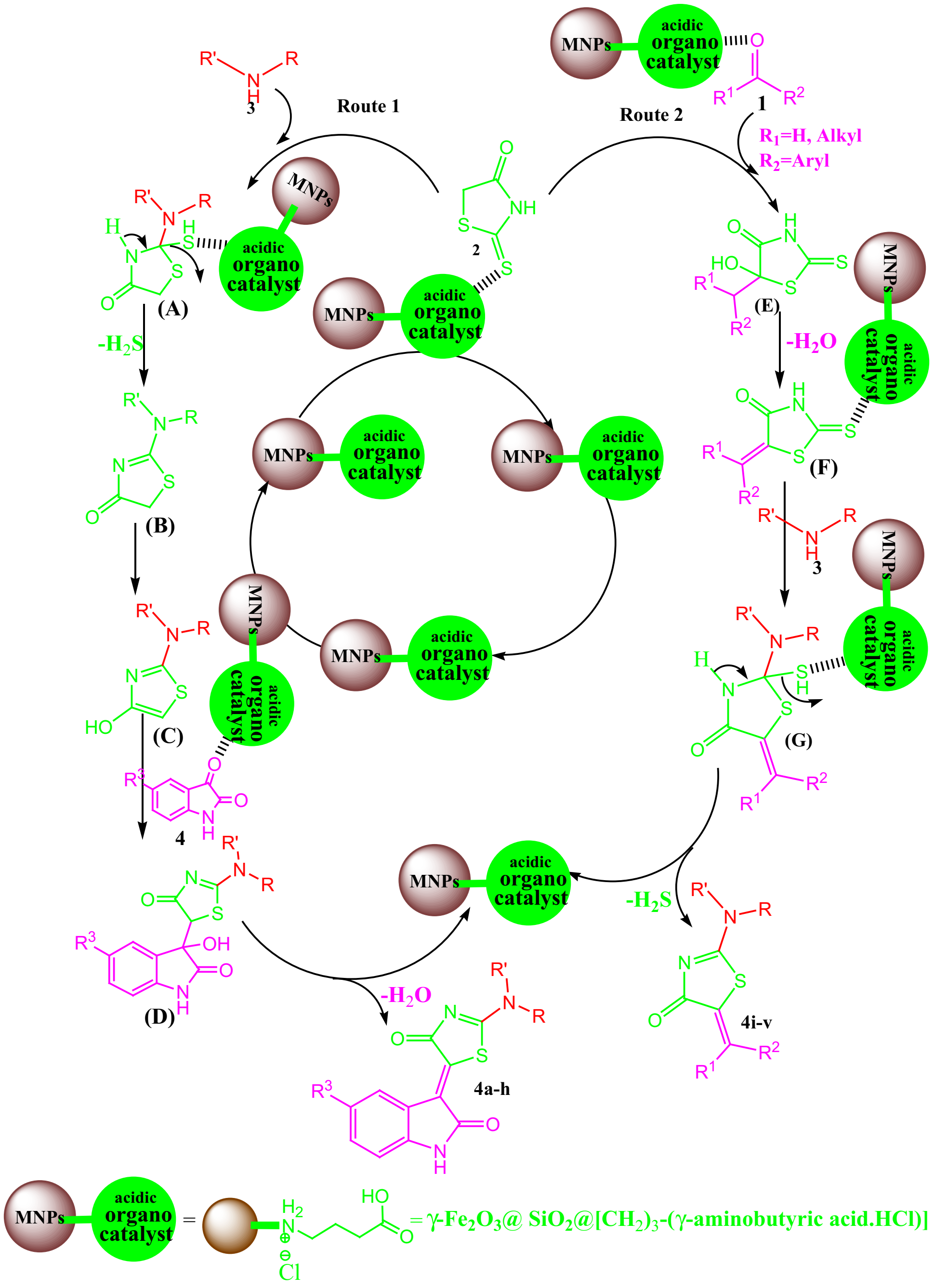
15			 4o	65	90	236-239	236-238 [18]
16			 4p	60	93	233-236	234-236 [18]
17			 4r	65	90	237-240	236-237 [21]
18			 4s	60	90	180-183	New compound
19			 4t	60	92	210-213	New compound
20			 4u	55	90	213-215	New compound
21			 4v	60	95	185-187	New compound

[a]Reaction conditions: rodanine(1 mmol), aromatic carbonyl compounds (1mmol) and primary or secondary amines (1 mmol) in Water:ethanol (2:1) (3ml); [b]Yield refer to isolated pure products.



Scheme 4 The proposed mechanism for the synthesis of 2-amino-5-alkylidene-thiazol-4-one derivatives in the presence of nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid. HCl)] as superparamagnetic nanocatalyst

Experimental

Materials and Methods

All materials were purchased from Merck and Aldrich Company. The NMR spectra were provided on Brucker Avance 300 MHz instruments in DMSO-d_6. Melting points were determined in open capillaries using a BUCHI510 melting point apparatus. The progress of the reactions was monitored by TLC. Thin-layer chromatography (TLC) was performed on silica-gel Poly Gram SIL G/UV 254 plates. The characterization of MNPs-organocatalyst as a catalyst was performed according to FT-IR spectra which recorded using KBr disks on a JASCO FT-IR 460 plus spectrophotometer and elemental compositions were determined with a Leo 1450 VP scanning electron microscope equipped with an SC7620 energy-dispersive spectrometer (SEM-EDS) presenting a 133 eV resolution at 20 kV. Power X-ray diffraction (XRD) was performed on a Bruker D8-advance X-ray diffractometer with Cu Kα ($\lambda = 0.154$ nm) radiation. The magnetic property of γ-Fe_2O_3 supported was measured with (VSM/AGFM). TGA was done on a thermal analyzer with

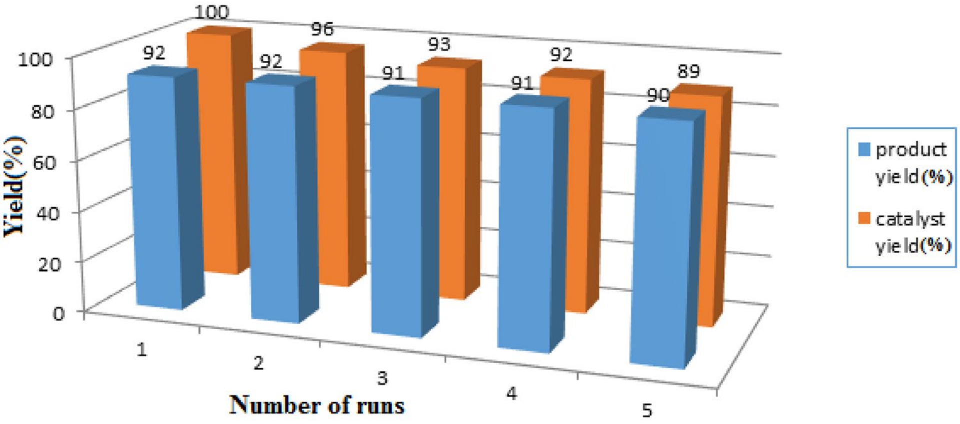


Fig. 8 Reusability of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)]

a heating rate of 10 °C min^{-1} over a temperature range of 25–800 °C under flowing compressed N_2.

Preparation of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] as a superparamagnetic heterogeneous nanocatalyst

Preparation of γ-Fe_2O_3

The Fe_3O_4 nanoparticles were prepared according to a previously reported procedure [20]. $FeCl_2.4H_2O$ (1.25 g) and $FeCl_3.6H_2O$ (3.33 g) were dissolved in water (80 mL) separately, followed by the two iron salt solutions being mixed under continuously stirring (800 rpm). Then, a NH_4OH solution (%25, 60 mL) was drop added to the stirring mixture at room temperature for 3 h and stirring continued for 1 h; the black products were collected by an external magnet. Then, Fe_3O_4 MNPs were washed three times with water and ethanol, and dried at 60 °C for 12 h. Fe_3O_4 nanoparticles at this stage are heated at 300 °C in a furnace for 3 h to convert Fe_3O_4 to sustainable γ-Fe_2O_3 nanoparticles.

Preparation of γ-Fe_2O_3 @SiO_2

γ-Fe_2O_3 nanoparticles (1 g) were dispersed in ethanol (40 mL) and the resulting mixture was stirred for 1 h at 40 °C. Subsequently, tetraethyl orthosilicate (TEOS, 2 mL) was charged to the reaction vessel, and the mixture was continuously stirred for 24 h. The silica-coated nanoparticles were collected by an external magnet, followed by washing three times with ethanol and drying at 70 °C for 12 h causing the formation of γ-Fe_2O_3 @SiO_2.

Preparation of chloro-functionalized γ-Fe_2O_3@SiO_2

γ-Fe_2O_3@SiO_2 nanoparticles (1 g) were dispersed in ethanol (40 mL). After that (3-chloropropyl)triethoxysilane (0.5 mL) and ammonia solution(3 mL) were added to the dispersed ethanolic solution of γ-Fe_2O_3@SiO_2 and stirred for 24 h at room temperature. The silica-coated nanoparticles by an external magnet were collected, followed by washing three times with ethanol and drying at 70 °C for 12 h.

Preparation of nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid. HCl)] as a superparamagnetic nanoparticles

The chloro-functionalized γ-Fe_2O_3@SiO_2 (1 g) was dispersed in 30 mL distilled water and γ-aminobutyric acid (1 g) dissolved in 50 mL ethanol–water (1:1) was added to the dispersed MNPs and the reaction mixture stirred at room temperature for 24 h. The MNPs-organocatalyst was then isolated by simple magnetic decantation, sequentially washed with water and ethanol three times, and finally dried at 60 °C for 12 h. The successful synthesis of MNPs-organocatalyst was confirmed by the FT–IR, EDX, SEM, TGA, VSM, and XRD analyses.

General procedure for the direct synthesis of 2-amino-5-alkylidene-thiazol-4-one derivatives (4a–h) using nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid. HCl)] catalyst.

Nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] (5 mg) was added to a mixture rodanine (1 mmol), primary or secondary amines (1 mmol) and stirred at room temperature in water:ethanol (2:1) (3 ml) for some minutes; then, isatins (1 mmol) were added to a mixture reaction. After completion of reaction, the solvent was separated by filtration, and ethanol was added to the reaction mixture and heated to separate nano-γ-Fe_2O_3@SiO_2@$[CH_2)_3$-(γ-aminobutyric acid.HCl)] by external magnet. The catalyst was washed with ethanol for three times and dried. The warm ethanolic solution containing crude product was cooled until precipitated pure product was formed. The known pure products were characterized and compared their physical data with those of known compounds. The characterization of new unknown products was represented as below.

General procedure for the direct synthesis of 2-amino-5-alkylidene-thiazol-4-one derivatives (4i–v) using nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid.HCl)] as catalyst.

Nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid.HCl)] (5 mg) was added to a mixture rodanine(1 mmol), aromatic carbonyl compounds(aldehydes or ketones) (1 mmol) and stirred at room temperature in water:ethanol(2:1) (3 ml) for some minutes, then primary or secondary amines (1 mmol) added to a mixture reaction. After the completion of reaction, the solvent was separated by filtration, ethanol was added to the reaction mixture and heated to separate nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid.HCl)] by external magnet. The catalyst was washed with ethanol for three times and dried. The warm ethanolic solution containing crude product was cooled until precipitated pure product was formed. The known pure products were characterized and compare their physical data with those of known compounds. The characterization of new unknown products is represented as below.

Experimental characterization data and spectra of the new compounds.

5-(Benzylidene)-4′,5′-dihydro-[2, 2′] bithiazolyl-4-one (4s)

Yellow solid; mp:180–183 °C. IR (KBr) (νmax /cm^{-1}): 3272, 3041, 2851, 1669, 1285. ^{1}H NMR (300 MHz, DMSO-d_6): δ_H (ppm) 3.54–3.59 (2H, t, $J = 7.52$ Hz, CH_2), 3.87–3.92 (2H, t, $J = 7.52$ Hz, CH_2), 7.40 (1H, s, =CH),7.43–7.58 (4H, m, H-Ar), 9.94(1H,w,NH). ^{13}C NMR (75 MHz, DMSO-d_6): δ_C (ppm) 31.60, 49.22, 127.93, 129.66, 130.01, 130.48, 131.36, 134.58 ,173.24, 177.72, 200.43.

5-(4-Chloro-benzylidene)-4′,5′-dihydro-[2, 2′] bithiazolyl-4-one (4t)

Yellow solid; mp:210–213 °C. IR (KBr) (νmax /cm^{-1}): 3289, 3046,2851, 1669,1275. ^{1}H NMR (300 MHz, DMSO-d_6): δ_H (ppm) 3.54–3.59 (2H, t, $J = 7.52$ Hz, CH_2), 3.87–3.92 (2H, t, $J = 7.52$ Hz, CH_2), 7.31 (1H, s, =CH),7.55 (4H, m, H-Ar), 9.37(1H,w,NH). ^{13}C NMR (75 MHz, DMSO-d $_6$): δ_C (ppm) 31.57, 49.17, 127.35, 129.72, 130.94, 131.61, 133.22,134.82 ,173.28, 175.84, 199.05.

5-(4-Bromo-benzylidene)-4′,5′-dihydro-[2 2′] bithiazolyl-4-one (4u)

Yellow solid; mp: 213–215 °C. IR (KBr) (νmax /cm^{-1}): 3291, 2044, 2847,1668, 1272. ^{1}H NMR (300 MHz, DMSO-d_6): δ_H (ppm) 3.54–3.59 (2H, t, $J = 7.52$ Hz, CH_2), 3.87–3.92 (2H, t, $J = 7.52$ Hz, CH_2), 7.39 (1H, s, =CH),7.47–7.71 (4H, m, H-Ar), 9.52(1H,w,NH). ^{13}C NMR (75 MHz, DMSO-d_6): δ_C (ppm) 31.56, 49.18, 123.52, 126.87, 131.77, 132.26, 132.64, 133.73 ,173.24, 176.82, 199.53.

5-(3-Methyl-benzylidene)-4′, 5′-dihydro-[2, 2′] bithiazolyl-4-one (4v)

Yellow solid; mp:185–187 °C. IR (KBr) (νmax /cm^{-1}): 3281, 3074, 2850, 1694, 1291. ^{1}H NMR (300 MHz, DMSO-d_6): δ_H (ppm) 2.37(3H,s, CH_3) 3.53–3.58 (2H, t, $J = 7.52$ Hz, CH_2), 3.86–3.91 (2H, t, $J = 7.52$ Hz, CH_2), 7.28–7.45 (4H, m, H-Ar),7.50 (1H, s, =CH),9.33(1H,w,NH). ^{13}C NMR (75 MHz, DMSO-d_6): δ_C (ppm) 21.40, 31.52, 49.17, 127.82, 127.97, 129.71, 130.58, 131.20, 131.51, 133.85, 139.15,172.73, 173.23, 197.70.

Conclusion

Nano-γ-Fe_2O_3@SiO_2@$[CH_2]_3$-(γ-aminobutyric acid.HCl)] as a novel organometallic heterogeneous nano-magnetic catalyst has been successfully synthesized and characterized by the several techniques such as XRD, FT-IR, VSM, FE-SEM, EDS, and TGA-DTG analysis. This efficient nano-organometallic catalyst was successfully used for the three-component preparation of 2-amino-5-alkylidene-thiazol-4-one derivatives under green conditions. Easy reaction conditions, simple work-up, or purification, excellent yields, high purity of the desired product, atom economy, and short reaction times are some advantages of this protocol. The superparamagnetic nanocatalyst is magnetically separable and stable in the reaction conditions without detectable activity loss.

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References

1. W. Liu, D. Wang, Y. Duan, Y. Zhang, F. Bian, Tetrahedron Lett. **56**, 1784 (2015)
2. Q. Luo, X. Xiao, X. Dai, Z. Duan, D. Pan, H. Zhu, X. Li, L. Sun, K. Luo, Q. Gong, ACS Appl Mater. Interfaces. **10**, 1575 (2018)
3. P. Eghbali, H. Fattahi, S. Laurent, R.N. Muller, Y. Mosaei Oskoei, J. Iran. Chem. **13**, 87 (2016)
4. R.S. Varma, ACS Sustain. Chem. Eng. **4**, 5866 (2016)
5. R. Mrówczyński, ACS Appl. Mater. Interfaces. **10**, 7541 (2018)

6. M. L.Tong, S. Zhao, J. Zhu, Chen, J. Iran. Chem. **5**, 379 (2011)
7. M.A. Bodaghifard, S. Asadbegi, Z. Bahrami, J. Iran. Chem. 14, 365 (2017)
8. D. Wang, C. Deraed, J. Ruiz, D. Astruc, Acc. Chem. Res. **48**, 1871 (2015)
9. Z. Lei, B. Chen, Y.M. Koo, D.R. MacFarlane, Chem. Rev. **11**, 6633 (2017)
10. D. Zhao, Y. Liao, Z. Zhang, Clean Soil Air Water Clean **35**, 42 (2007)
11. N. Ahmed, Z.N. Siddiqui, J. Mol. Catal. A Chem. **387**, 45 (2014)
12. R. Vaid, M. Gupta, V.K. Gupta, J. Iran. Chem **14**, 2199 (2017)
13. M. Tanhaei, A. Mahjoub, R. Nejat, Catal Lett. **148**, 1549 (2018)
14. A. Khalatbari Jafari, R. Kardanpour, S. Tangestaninejad, V. Mirkhani, M. Moghadam, I. Mohammadpoor-Baltork, F. Zadehahmadi, J. Iran. Chem. **5**, 997 (2018)
15. S. Kazemi Movahed, R. Esmatpoursalmani, A. Bazgir, RSC Adv. **4**, 14586 (2014)
16. R. Baharfar, N. Shariati, C. R. Chim. **17**, 413 (2014)
17. C. Mukhopadhyay, S. Ray, Tetrahedron **67**, 7936 (2011)
18. C. Mukhopadhyay, S. Ray, Tetrahedron Lett. **52**, 6431 (2011)
19. H. Mohamadi, H.R. Shaterian, Res. Chem. Intermed. https://doi.org/10.1007/s11164-018-3571-1
20. H.N. Dadhania, D.K. Raval, A.N. Dadhania, Catal. Sci. Technol. **5**, 4806 (2015)
21. M. Anderluh, M. Jukic, R. Petric, Tetrahedron **65**, 344 (2009)