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An Update on Half-decade Recent Advances in Functionalized Fe_3O_4 Nanoparticles as Heterogeneous Nanocatalysts for the Synthesis of Six-Membered Compounds Containing Nitrogen: A Mini-Review

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ABSTRACT

Over the past half-decade, the functionalized Fe_3O_4 nanoparticles have been applied to organic synthesis as heterogeneous nanocatalysts. Due to the magnetic properties, the functionalized Fe_3O_4 nanoparticles have been preferred over other catalytic systems. In addition, the unique physical, chemical, and magnetic field properties of Fe_3O_4 nanoparticles have led to the development of them for efficient organic synthesis as heterogeneous catalytic systems. Over the past half-decade, all the researchers tried to design and develop different functionalized Fe_3O_4 nanoparticles to perform the organic transformation. In this mini-review, different methodologies for the synthesis of six-membered compounds (heterocyclic compounds) containing nitrogen catalyzed by functionalized Fe_3O_4 nanoparticles have been reviewed. This short review aims to comprehensively investigate the use of functionalized Fe_3O_4 nanoparticles in the synthesis of six-membered compounds (heterocyclic compounds) containing nitrogen with emphasis on their reusability of the catalysts and magnetic field of them in separation from the organic reaction medium.

***Keywords**: Fe_3O_4 nanoparticles, heterocyclic compounds, magnetic, nanocatalyst, synthesis, reusability*

1. Introduction

Since the first research paper in 1916 titled "The oxides of iron. I. Solid solution in the system Fe_2O_3-Fe_3O_4" by Sosman and Hostetter, the Fe_3O_4 topic has grown into the main research area [1]. In this short review, we aim to present a wide overview of the functionalized Fe_3O_4 nanoparticles as a recoverable and magnetically reusable nanocatalyst. In particular, the main focus of this study is on the use of functionalized Fe_3O_4 nanoparticles in the synthesis of six-membered compounds (heterocyclic compounds) containing nitrogen such as pyridobenzoazepines, 2-amino-3-cyanopyridine, pyrido[2,1-a]isoquinolines, pyrido[1,2-a]quinolones, and so on. 36549 articles were found in a search on 31st March 2022 on the Scopus website for the term "Fe_3O_4" in articles title, abstract, and keywords. In **Fig. 1** the different applications of Fe_3O_4 in various fields of sciences are presented. In addition, there is a growing number of published original articles on Fe_3O_4 nanoparticles in organic synthesis. To the best of our knowledge, this is the first review paper about the application of functionalized Fe_3O_4 nanoparticles in the synthesis of six-membered compounds (heterocyclic compounds) containing nitrogen. Therefore, we decided to start a review paper on this matter.

Pharmaceutical and medicinal chemistry are interesting filed in organic synthetic chemistry for the preparation

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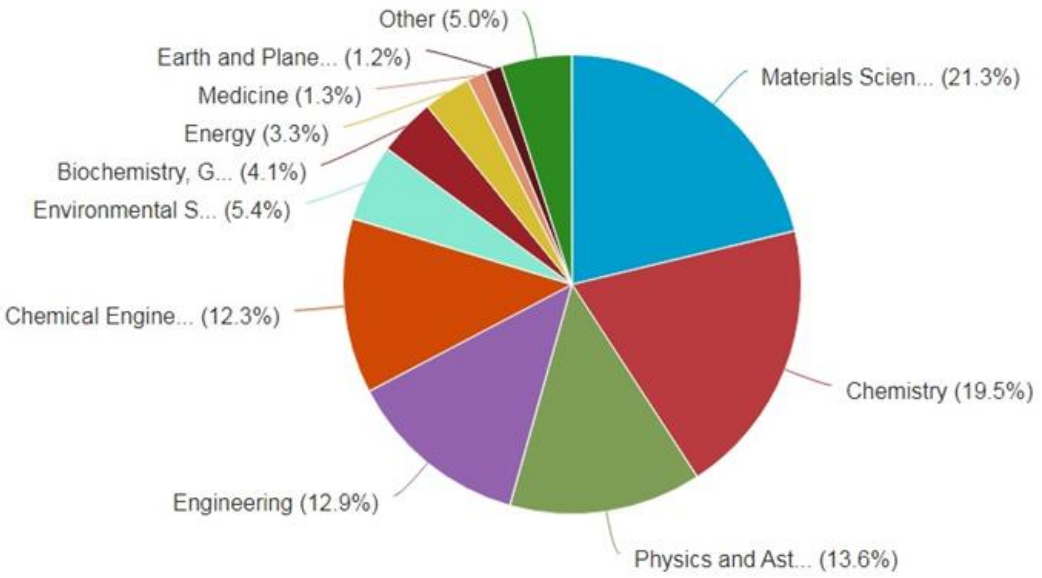


Fig. 1. Application of Fe_3O_4 nanoparticles in different fields of sciences

of different biologically active compounds dealing with drug effectiveness. In addition, nitrogen heterocyclic compounds especially six-membered rings more attention in scientific research papers [2-11]. The heterocyclic six-membered ring compounds are widely spread in the drug and natural compounds. The chemical structure of some of these compounds is shown in **Fig 2**.

2. Synthesis of Six-Membered Heterocyclic Compound Containing Nitrogen Catalyzed by Functionalized Fe_3O_4 Nanoparticles

In 2022, Savari and co-workers described the synthesis of new compounds of pyridobenzoazepines in the presence of Ag-Fe_3O_4-TiO_2-MWCNTs at room temperature in the water as a green solvent [12] (**Scheme 1**). In this research, the Ag-Fe_3O_4-TiO_2-MWCNTs nanocomposites were prepared via biology and green route using *S. oleracea* bacteria. At first, they synthesized Ag-Fe_3O_4-TiO_2 using $AgNO_3$, $FeCl_3$, and $FeCl_3$ in the presence of *S. oleracea* as a green reducing agent to reduce Ag (I) to Ag nanoparticles. Subsequently, 0.1 g of multi-walled carbon nanotubes (MWCNTs) was added to the Ag-Fe_3O_4-TiO_2 under ultrasound irradiation. Then, the prepared composite was heated at 500 °C for 45 min and washed with the mixture of water and ethanol to obtain pure Ag-Fe_3O_4-TiO_2-MWCNTs nanocomposites. The interesting characteristic of the pointed catalyst was its attraction to an external magnet. After preparation of the catalyst, to synthesize pyridobenzoazepines, a mixture of isatoic anhydride **1** (2 mmol), *N*-methylimidazole **2** (2 mmol), activated acetylinic **3** and **4** (2 mmol) in the presence of 0.015 g of Ag-Fe_3O_4-TiO_2-MWCNTs nanocomposites for 15 min. Then, 2 mmol of α-haloketone **5** and ammonium acetate **6** were added and stirred for 20 other min. Finally, 2 mmol of 2-methyloxirane (epoxide) **7** was added and stirred in water for 1 h to obtain corresponding compounds **8** and **9** in 83-96% yield. If R in compound **4** was hydrogen the compound **8** could be formed. In the current study, the Ag-Fe_3O_4-TiO_2-MWCNTs nanocomposite shows reusability for seven catalytic cycles in 92% to 87% yield. Notably, some of the synthesized pyridobenzoazepine derivatives show antioxidant activity towards DPPH radical trapping through the FRAP method. The good to excellent yield, moderate reaction time, and high atomic economic, as well as ambient temperature are some of the worthwhile advantages of the presented method.

In 2021, Motahari and Khazaei reported an efficient approach for the synthesis of 2-amino-3-cyanopyridine derivatives **13** using Fe_3O_4-SiO_2-Si-$(CH_2)_3$NH-CC-Im-Co (II) nanoparticles at 100 °C under solvent-free conditions (**Scheme 2**) [13]. The 2-amino-3-cyanopyridine derivatives **13** have biological activity including anti-HIV, anti-acid, and anti-tumor. They prepared the Fe_3O_4-SiO_2-Si-$(CH_2)_3$NH-CC-Im-Co (II) nanoparticles through the five sequence steps involving (i): preparation of Fe_3O_4-SiO_2 (ii): supporting 3-aminopropyltriethoxy silane on Fe_3O_4-SiO_2 (iii): addition of cyanuric chloride to obtain Fe_3O_4-SiO_2-Si-$(CH_2)_3$NH-CC, (iv): addition of imidazole to Fe_3O_4-SiO_2-Si-$(CH_2)_3$NH-CC to afford Fe_3O_4-SiO_2-Si-$(CH_2)_3$NH-CC-Im, and (v): using $Co(OAc)_2$ as

precarious source of cobalt to form Fe_3O_4-SiO_2-Si-$(CH_2)_3$NH-CC-Im-Co (II) nanoparticles. The chemical representation of the catalyst was shown in **Fig. 3**. After the preparation of the pointed catalyst, they used a mixture of 1 mmol of aryl aldehydes **10**, 1 mmol of acetophenones **11**, 1 mmol of malononitrile **12**, and 1.25 mmol of ammonium acetate **6** in the presence of 0.05 g of Fe_3O_4-SiO_2-Si-$(CH_2)_3$NH-CC-Im-Co (II) at 100 °C under solvent-free conditions. The Fe_3O_4-SiO_2-Si-$(CH_2)_3$NH-CC-Im-Co (II) show reusability for eight consequence catalytic cycles.

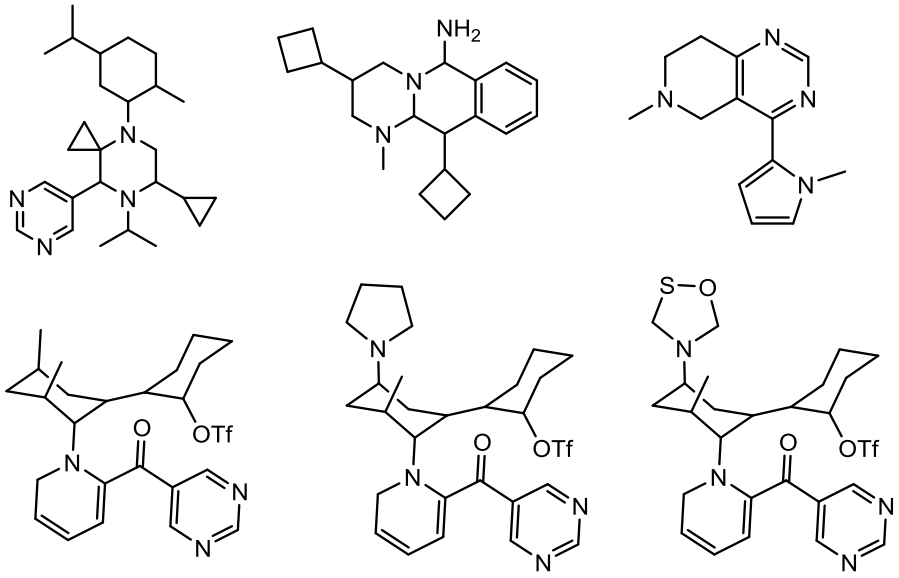
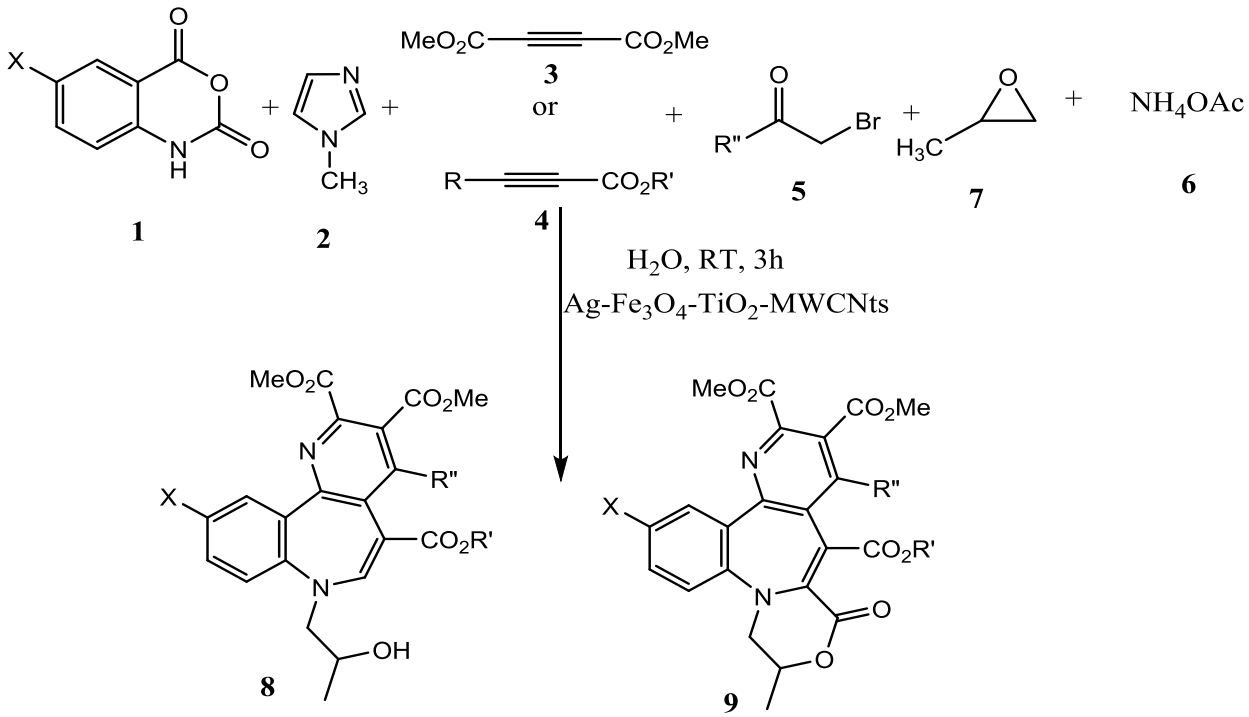
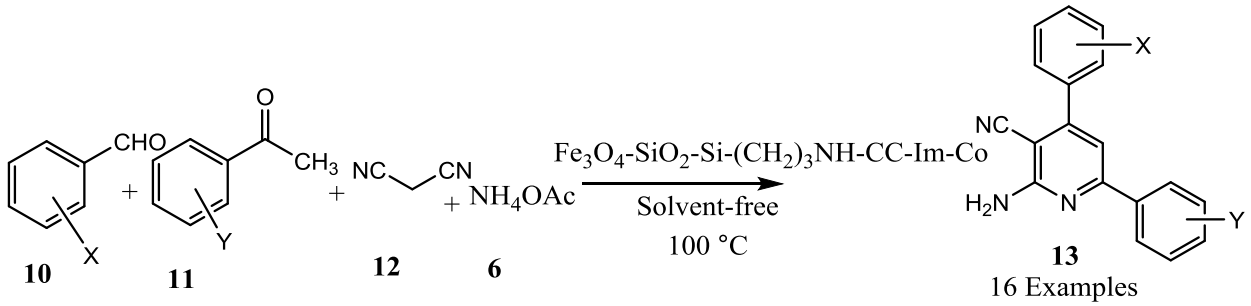


Fig. 2. Some of the biologically active of six-membered nitrogen compounds



Scheme 1. Synthesis of pyridobenzoazepine derivatives using Ag-Fe_3O_4-TiO_2-MWCNTs nanocomposites



Scheme 2. Synthesis of 2-amino-3-cyanopyridine derivatives using Fe_3O_4-SiO_2-Si-$(CH_2)_3$NH-CC-Im-Co (II) nanoparticles

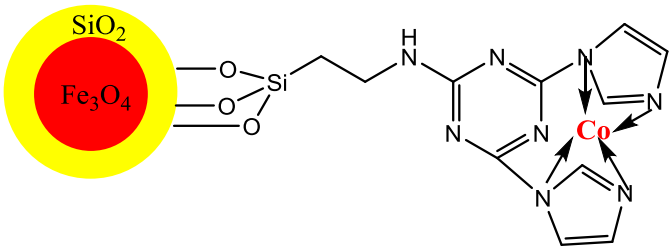
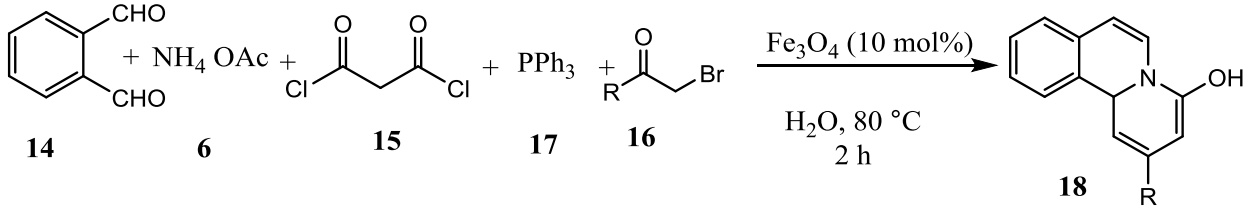


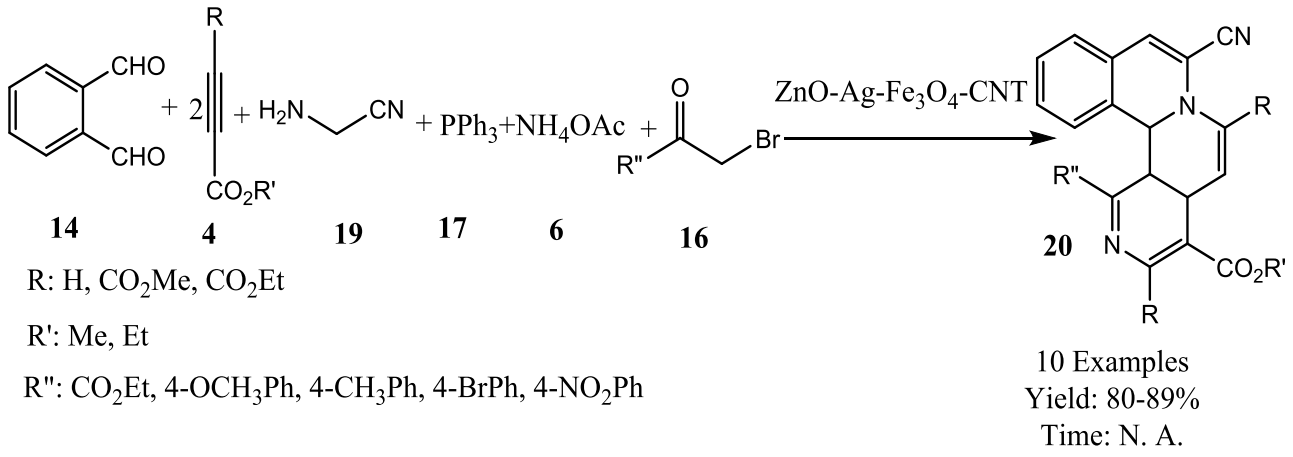
Fig. 3. The schematic of Fe_3O_4-SiO_2-Si-$(CH_2)_3$NH-CC-Im-Co (II) nanoparticles.

In 2021, Ezzatzadeh and co-workers described a green method for the synthesis of pyrido[2,1-a]isoquinolines and pyrido[1,2-a]quinolones **18** using bio-Fe_3O_4 nanoparticles (**Scheme 3**) [14]. In this multicomponent reaction, in the mixture of 2 mmol of phthaldehyde **14**, 2 mmol of ammonium acetate **6**, 2 mmol of malonyl chloride **15**, α-bromoketone **16**, and triphenylphosphine **17** the final products **18** were obtained in good to excellent yields within 2 h. The optimum reaction conditions were 10 mol% of Fe_3O_4 nanoparticles, water as the solvent, and 80 °C. Notably, they synthesized Fe_3O_4 nanoparticles via the reduction of ferric chloride solution using Clover leaf water. In addition, they investigated some of the antioxidant activity of the prepared pyrido[2,1-a]isoquinolines and pyrido[1,2-a]quinolones using DPPH trapping in the presence of TBHQ and BHT as antioxidant references. Moreover, the antimicrobial activity of pyrido[2,1-a]isoquinolines and pyrido[1,2-a]quinolones were checked and the obtained results showed that some of the pointed compounds were active in the diffusion test on Gram-positive and Gram-negative bacteria.

In 2021, Hossaini and co-workers developed a new strategy for the synthesis of naphthyridines **20** using the mixture of phthaldehyde **14**, 2-aminoacetonitrile **19**, activated acetylinic compounds **4**, triphenyl phosphine **17**, ammonium acetate **6**, and α-bromoketone **16** in the presence of ZnO-Ag-Fe_3O_4-CNTs nanoparticles in aqueous media (**Scheme 4**) [15]. In this research, they investigated antioxidant properties of some of the synthesized compounds by DPPH radical trapping. In addition, the antimicrobial activity of the synthesized compounds was checked. Their results showed that the synthesized compounds have high biological activity such as antioxidant and antimicrobial activity. They prepared the ZnO-Ag-Fe_3O_4-CNTs nanoparticles using the following procedure: First, 0.5 g of $AgNO_3$, 1 g of $Zn(OAc)_2$, and 1.5 g of $FeCl_2.4H_2O$ were added to 100 mL of *Petasites hybridus rhizome* water extract to afford the colloids of AgOH, $Zn(OH)_2$, and $Fe(OH)_2$ at ambient temperature. Then, the pointed colloids were heated to 350 °C for 2 h to obtain brown solid ZnO-Ag-Fe_3O_4. In continue, 0.1 g of ZnO-Ag-Fe_3O_4 and 0.1 g of carbon nanotubes (CNTs) were mixed in 100 mL of *P. hybridus rhizome* water extract under ultrasound irradiation at 100 °C. Then, the obtained black solid was washed several times with water and ethanol to produce ZnO-Ag-Fe_3O_4-CNTs nanoparticles.



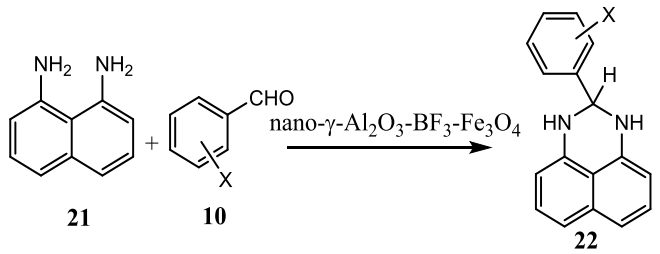
Scheme 3. Synthesis of pyrido[2,1-a]isoquinolines and pyrido[1,2-a]quinolones using bio-Fe_3O_4 nanoparticles



Scheme 4. Synthesis of naphthyridines in the presence of ZnO-Ag-Fe_3O_4-CNTs nanoparticles

In 2021, Mazoochi and co-workers established different new methods for the synthesis of 2,3-dihydroperimidines **22** in the presence of nano-γ-Al_2O_3-BF_3-Fe_3O_4 nanoparticles under grinding, reflux, microwave, and ultrasound conditions (**Scheme 5**) [16]. The 2,3-dihydroperimidines **22** were synthesized using the reaction of naphthalene-1,8-diamine **21** and aryl aldehydes **10** under grinding, reflux, microwave, and ultrasound irradiations. The catalytic amount of nano-γ-Al_2O_3-BF_3-Fe_3O_4 and nano-γ-Al_2O_3-BF_3 for grinding, reflux, microwave, and ultrasound conditions were (0.06, and 0.12 g), (0.06, and 0.06 g), (0.06, and 0.03 g), and (0.03, and 0.03 g), respectively. They investigated the chemical structure of the synthesized compounds using ^{1}H NMR, ^{13}C NMR, and melting point. Their results show that ultrasound irradiation was the best reaction condition due to the reaction time and yield of the final products for the synthesis of 2,3-dihydroperimidines **22.** In addition, the reusability of the catalyst was checked and the pointed catalyst showed five consequence catalytic cycles.

In 2020, Moussa and Rahmati designed a new catalyst (Fe_3O_4-SiO_2-TEAPOM) for the synthesis of tetrahydrobenzimidazo[2,1-b]quinazolin-1(2H)-ones **26** via a multicomponent reaction including 2-aminobenzazoles **23**, benzaldehyde **24**, and cyclic β-diketone **25** in ethanol at 70-75 °C to obtain tetrahydrobenzimidazo[2,1-b]quinazolin-1(2H)-ones **26** in moderate to excellent yields (**Scheme 6**) [17]. The chemical structure of Fe_3O_4-SiO_2-TEAPOM was shown in **Fig. 4**. The pointed catalyst was characterized by FT-IR, TGA, SEM, TEM, EDX, and VSM techniques. Due to the presence of polyoxometalate, the catalytic of Fe_3O_4-SiO_2-TEAPOM was superior in the synthesis of tetrahydrobenzimidazo[2,1-b]quinazolin-1(2H)-ones **26.** Interestingly, the pointed catalyst showed excellent reusability up to ten catalytic cycles. Easy separation of the Fe_3O_4-SiO_2-TEAPOM using an external magnetic field, and green solvent were other worthwhile advantages of the presented work.



Scheme 5. Synthesis of 2,3-dihydroperimidines in the presence of nano-γ-Al_2O_3-BF_3-Fe_3O_4 nanoparticles under grinding, reflux, microwave (MW), and ultrasound (US) conditions.

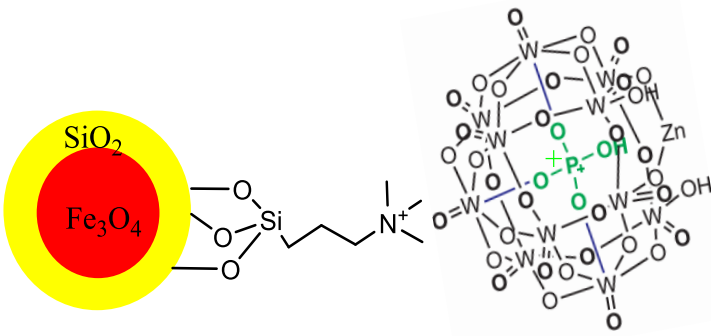
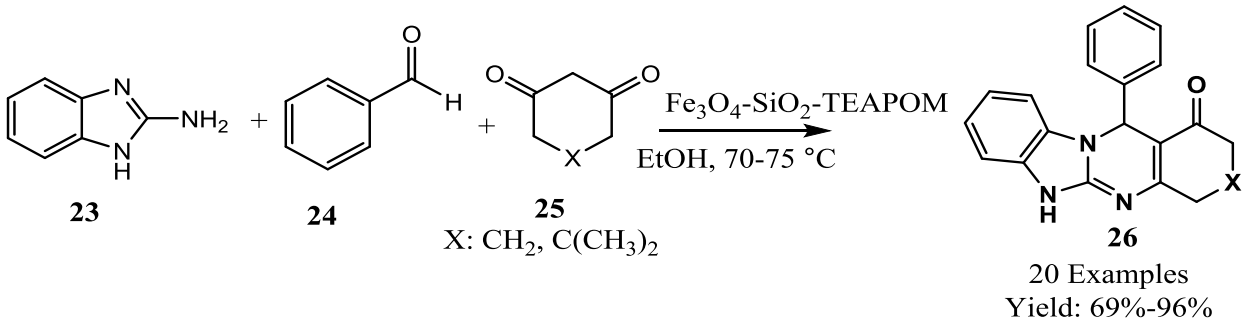


Fig. 4. The schematic representation of Fe_3O_4-SiO_2-TEAPOM

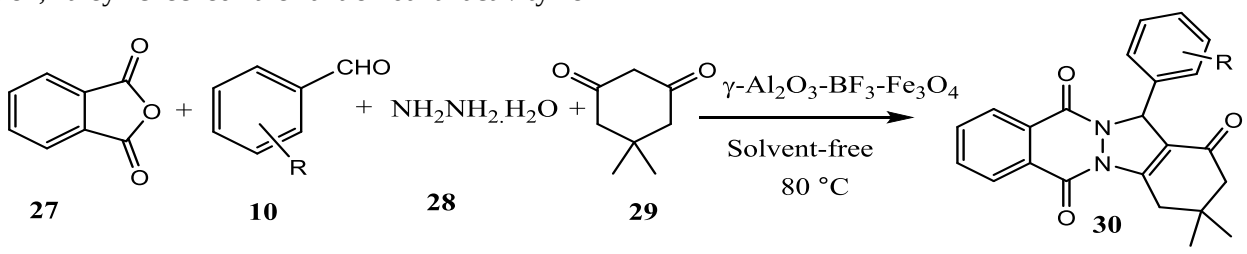


Scheme 6. Synthesis of tetrahydrobenzimidazo[2,1-b]quinazolin-1(2H)-ones using Fe_3O_4-SiO_2-TEAPOM

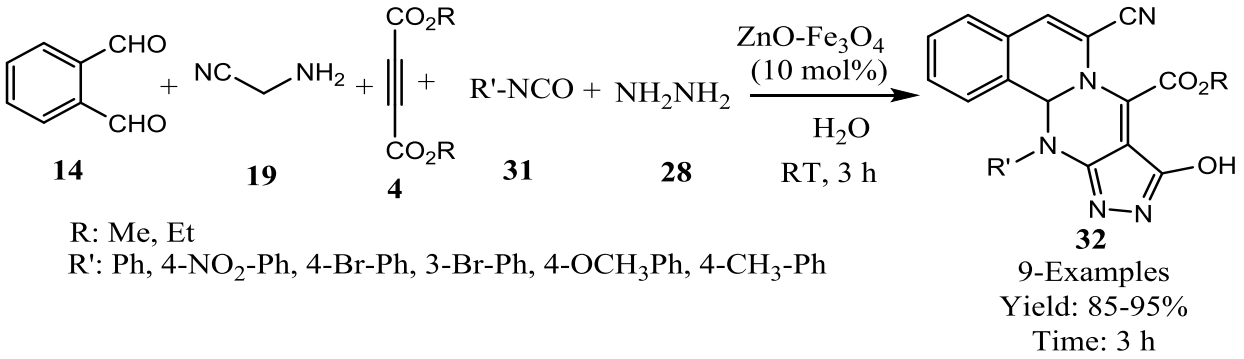
In 2020, Chegeni and co-workers described the synthesis of 2H-indazolo[2,1-b]phthalazine-triones **30** using nano-γ-Al_2O_3-BF_3-Fe_3O_4 nanoparticles at 80 °C under solvent-free conditions (**Scheme 7**) [18]. The 2H-indazolo[2,1-b]phthalazine-triones **30** was prepared through the reaction of phthalicanhydride **27**, aryl aldehyde **10**, hydrazine hydrate **28**, and dimedone **29** to produce 10 examples of 2H-indazolo[2,1-b]phthalazine-triones **30** in moderate to excellent yields within 10 to 56 min. The pointed catalyst could be reused for five consequence catalytic cycles with decreasing yield from 98% to 65% vs. increasing the reaction time from 12 min to 30 min. In addition, they calculated the HOMO-LUMO band gap ($\Delta E_{HOMO-LUMO}$) of the T1, T2 conformers of one of the synthesized compounds.

In 2020, Goochibeigi and co-workers promoted a green approach for the synthesis of pyrazolo pyrimidinone derivatives **32** in the presence of 10 mol% of ZnO-Fe_3O_4 nanoparticles at room temperature in water for 3 h (**Scheme 8**) [19]. In this regard, they prepared the pyrazolo pyrimidinone derivatives using a five component reactions including 2 mmol of phthaldehyde **14**, 2 mmol of cyano methylamine **19**, 2 mmol of dialkyl acetylene dicarboxylate **4**, and 2 mmol of isocyanate **31**, as well as hydrazine **28** in water using ZnO-Fe_3O_4 nanoparticles as a robust heterogeneous nanocatalyst. They reported 9 examples of pyrazolo pyrimidinone derivatives in good to excellent yields for 3 h. In addition, they checked the antioxidant activity of pyrazolo pyrimidinone and their results showed that the mentioned compounds have a great potential antioxidant activity towards DPPH radical trapping.

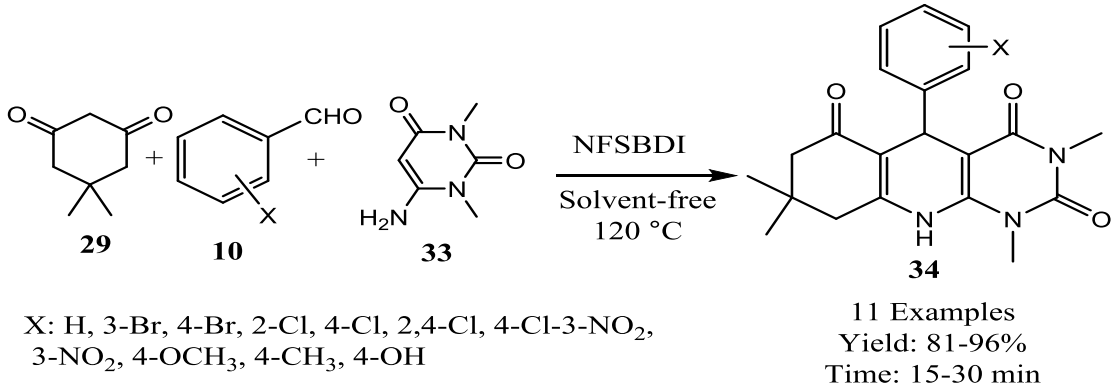
In 2020, Zare and Barzegar designed a new and fantastic heterogeneous catalyst for the synthesis of pyrimido[4,5-b]quinolones using NFSBDI as dicationic ionic liquid grafted with silica-coated nanoparticles of Fe_3O_4 (**Scheme 9**) [20]. The chemical structure of NFSBDI was shown in **Fig. 5**. They prepared NFSBDI using five consequences steps including (i) Fe_3O_4 preparation (ii), SiO_2 coated on Fe_3O_4 to afford Fe_3O_4-SiO_2, (iii) anchored of 3-chloropropyltrimethoxysilane on Fe_3O_4-SiO_2 to afford Fe_3O_4-SiO_2-SiPrCl, (iv) reaction of *N,N, N',N'*-tetramethylenediamine to obtain Fe_3O_4-SiO_2-$SiPrN(CH_3)_2CH_2CH_2N(CH_3)_2$, (iv) treatment of H_2SO_4 to corresponding dicationic ionic liquid grafted with silica-coated nanoparticles of Fe_3O_4 (NFSBDI). After preparation and characterization of NFSBDI as a heterogeneous catalyst, they synthesized some of the pyrimido[4,5-b]quinolones **34**, using the reaction of 1 mmol of dimedone **29**, 1 mmol of aldehyde **10**, and 1 mmol of 6-amino-1,3-dimethyluracil **33** in the presence of 0.048 g of NFSBDI to obtain pyrimido[4,5-b]quinolones **34** in good to excellent yields within 15-30 min. They characterized and approved the NFSBDI using FT-IR, FE-SEM, VSM, XRD, TGA, and EDS techniques. In addition, they investigated the reusability and recyclability of the catalyst and their results showed that the NFSBDI could be reused for four runs without loss of their catalytic activity.



Scheme 7. Synthesis of 2H-indazolo[2,1-b]phthalazine-triones using nano-γ-Al_2O_3-BF_3-Fe_3O_4 nanoparticles



Scheme 8. Synthesis of pyrazolo pyrimidinone derivatives using ZnO-Fe_3O_4 nanoparticles



Scheme 9. Synthesis of pyrimido[4,5-b]quinolones using NFSBDI

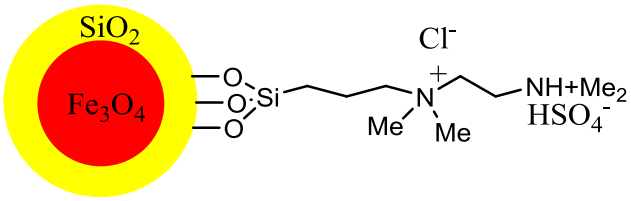
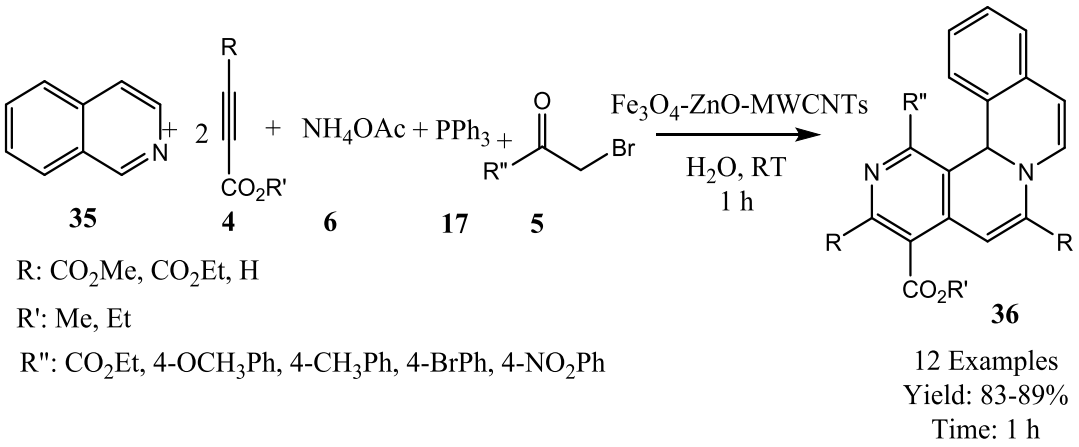


Fig. 5. The chemical structure of NFSBDI

In 2020, Hossaini and co-workers introduced the Fe_3O_4-ZnO-MWCNTs as high magnetic and efficient nanocomposites for the synthesis of naphthyridine **36** through a five-component reaction including isoquinoline **35**, dialkylacetylendicarboxylate **4**, α-haloketone **5**, triphenyl phosphine **17**, and ammonium acetate **6** (**Scheme 10**) [21]. They reported that the synthesized naphthyridine derivative has the potential for antimicrobial and anticancer activities. To approve the preparation of Fe_3O_4-ZnO-MWCNTs, they characterized the Fe_3O_4-ZnO-MWCNTs using SEM, TEM, EDX, XRD, and VSM techniques. The prepared catalyst can be reused for seven cycles. The easy separation of the catalyst using an external magnetic field, high yield of products, short reaction times, and biological activity of synthesized compounds were some of the worthwhile advantages of the pointed method.



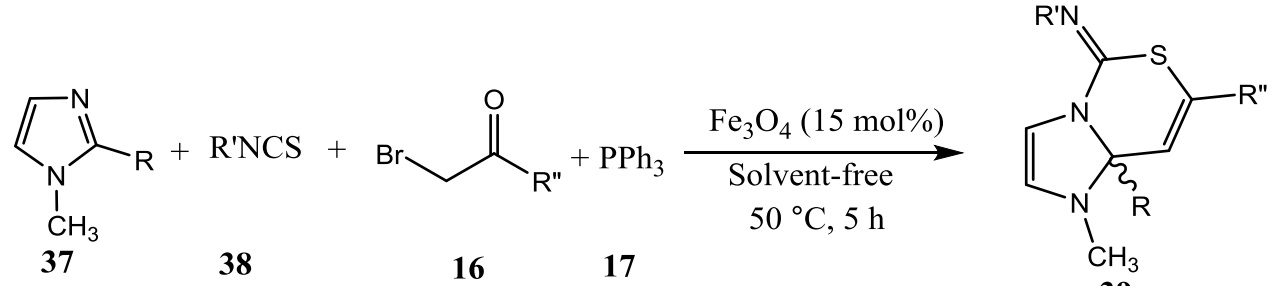
Scheme 10. Synthesis of naphthyridine using Fe_3O_4-ZnO-MWCNTs nanocatalyst

In 2019, Shafaei and Sharafian reported a green synthesis of imidazole derivatives **39** using 15 mol% of Fe_3O_4 nanoparticles at 50 °C for 5 h under solvent-free conditions (**Scheme 11**) [22]. They synthesized the imidazole derivatives **39** using a multicomponent reaction of N-methylimidazole **37**, isothiocyanate **38**, triphenyl phosphine **17**, and α-bromoketone **16**. It is notable that the Fe_3O_4 nanoparticles were synthesized through the green approach using the reduction of ferric chloride solution in the presence of *Clover Leaf* water extract.

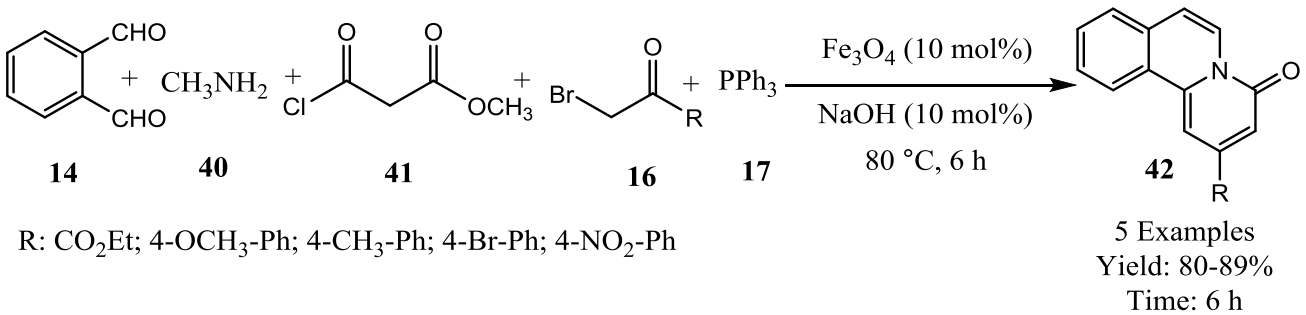
In 2019, Hamedian and co-workers described a green method synthesis of pyrido[2,1-*a*]isoquinolines and pyrido[1,2-*a*]quinolins **42** in the presence of 10 mol% of Fe_3O_4 nanoparticles and 10 mol% of sodium hydroxide at 80 °C for 6 h with good yields of the 5 examples of pyrido[2,1-*a*]isoquinolines and pyrido[1,2-*a*]quinolins (**Scheme 12**) [23]. In this work, they used phthaldehyde **14**, methyl amine **40**, methyl malonyl chloride **41**, triphenyl phosphine **17**, and α-bromoketone **16** to produce pyrido[2,1-*a*]isoquinolines and pyrido[1,2-*a*]quinolins **42**. In addition, they investigated the antioxidant activity of some of the synthesized compounds using DPPH radical trapping in comparison with BHT and TBHQ as references standard.

In China, Ashraf and co-workers reported a new method for the synthesis of polyhydroquinolines **44** in the presence of Fe_3O_4-Schiff base Cu as a heterogeneous catalyst in water (**Scheme 13**) [24]. The prepared catalyst was characterized by FT-IR, XRD, TEM, SEM, VSM, TGA, and ICP techniques. Then, they applied the Fe_3O_4-Schiff base Cu (**Fig. 6**) in the synthesis of polyhydroquinolines **44** using the reaction of 1 mmol of dimedone **29**, 1 mmol of aldehyde **10**, 1.3 mmol of ammonium acetate **6**, and 1 mmol of ethylacetoacetate **43** in the presence of 0.25 mol% of Cu in 3 mL of water under reflux conditions. Interestingly, they observed that the prepared catalyst could be reused for 11 catalytic cycles in the yield of 100% to 86% and turnover frequency of (TOF) (s^{-1}) 5760000-4953600.

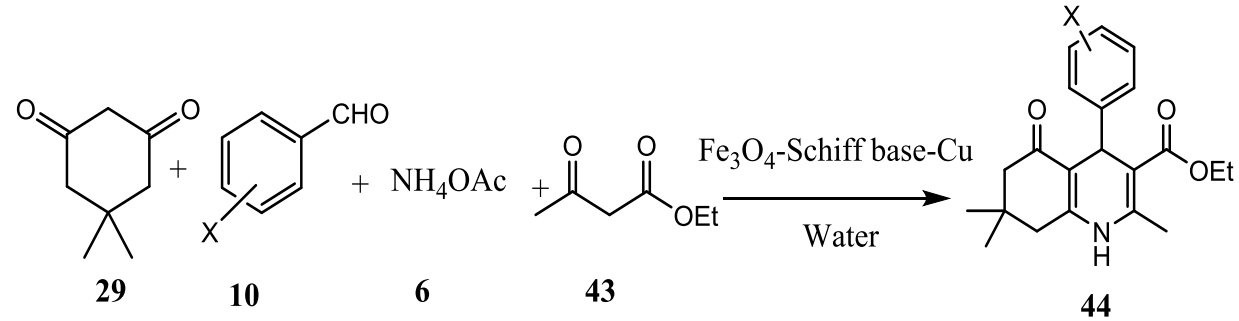
In 2019, Kalhor and Zarnegar developed a new multifunctional and magnetic nanocatalyst (Fe_3O_4/SO_3H@zeolite-Y) for the synthesis of perimidine derivatives in ethanol at room temperature (**Scheme 14**) [25]. In this regard, they used different aromatic aldehydes **10**, and 1,8-diaminenaphthalene **21** in the presence of 0.008 g of Fe_3O_4/SO_3H@zeolite-Y in ethanol at room temperature. Their results showed that both electron-withdrawing and electron-donating groups promoted the products in good to excellent yields. Also, the catalyst can be applied for five cycles.



Scheme 11. Synthesis of imidazole derivatives using bio Fe_3O_4 nanoparticles



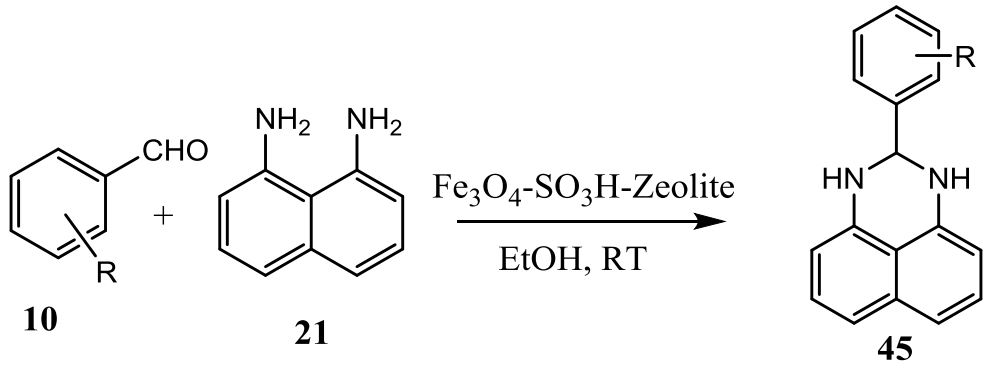
Scheme 12. Synthesis of pyrido[2,1-*a*]isoquinolines and pyrido[1,2-*a*]quinolins using Fe_3O_4 nanoparticles



X: 4-Cl, 4-CH_3, 4-OCH_3, 3,4-Di(OCH_3), 4-CF_3, 4-CN, H, 3-OH, 4-OH, 3,4-Di(OH), 4-Br, 3-Br, 4-F, 4-NO_2, 3-NO_2, 2-NO_{2-5}-OH, 4-$N(CH_3)_2$, 4-SCH_3

18 Examples
Yield: 90-100%
Time: 15-40 min

Scheme 13. Synthesis of polyhydroquinolines using Fe_3O_4-Schiff base Cu



R: H, 2-NO_2, 3-NO_2, 4-NO_2, 4-OCH_3, 3,4-OCH_3, 2-OH, 2-OH-5-Br, 2-OH-4-OCH_3, 3-Cl, 4-Cl, 2,3-Cl, 5-NO_2

13 Examples
Yield: 88-98%
Time: 3-6 min

Scheme 14. Synthesis of perimidine derivatives using Fe_3O_4/SO_3H@zeolite-Y

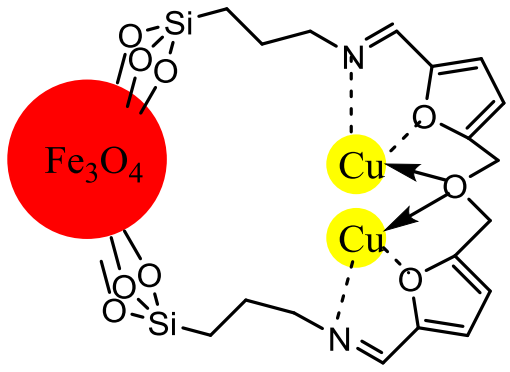
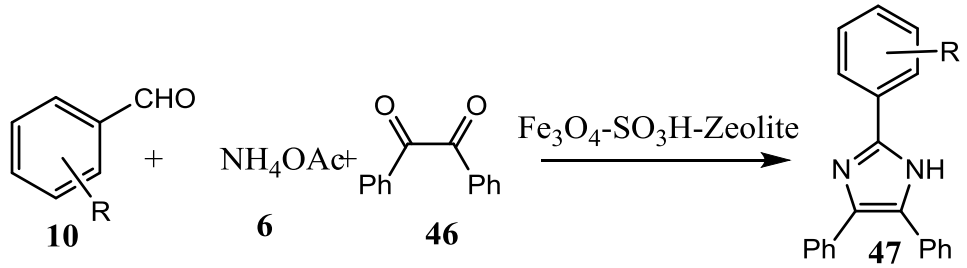


Fig. 6. The chemical structure of Fe_3O_4-Schiff base Cu

Furthermore, the same group reported the synthesis of various three substituted imidazole derivatives **47** via the reaction of 1 mmol of different aromatic aldehydes **10**, 2 mmol of ammonium acetate **6,** and 1 mmol of benzil **46** in the presence of 0.02 g of Fe_3O_4/SO_3H@zeolite-Y in ethanol at 80 °C (**Scheme 15**) [25]. All of the desired three substituted imidazoles **47** were obtained in good to excellent yields within 20-65 min. In addition, the pointed catalyst can be used for five consequence catalytic cycles.

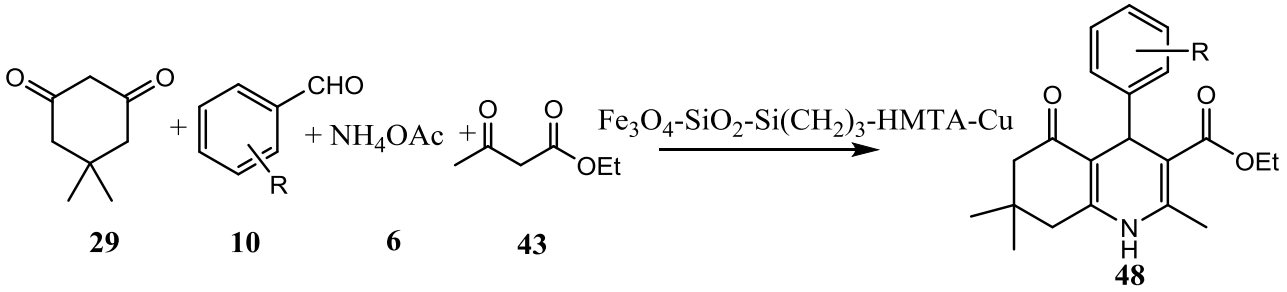
In 2019, the Fe_3O_4-SiO_2-SiPr-HMTA-Cu was prepared by Salem and co-workers for the synthesis of hexahydroquinoline derivatives **48** using the treatment of 1 mmol of dimedone **29**, 1 mmol of aromatic aldehydes **10**, 1.2 mmol of ammonium acetate **6**, and 1 mmol of beta-ketoester **43** in the presence of 0.05 g of Fe_3O_4-SiO_2-SiPr-HMTA-Cu at 60 °C (**Scheme 16**) [26]. They identified the prepared catalyst with different techniques including FT-IR, FE-SEM, TEM, VSM, and TGA. Their result approved that the metal copper was successfully chelated with hexamethylenetetramine (HMTA). The presented method has some advantages including high yield, short reaction times, easy separation of the catalyst and products, and excellent atomic economic conditions.



R: H, 2-NO_2, 3-NO_2, 3-OH-4-OCH_3, 2-OCH_3, 3,4-OCH_3, 3-OH, 4-OCH_3, 2-Cl, 2,3-Cl, 2,4-Cl, 4-Cl, 3-Br, 4-CH_3

14 Examples
Yield: 85-98%
Time: 20-65 min

Scheme 15. Synthesis of imidazole derivatives using Fe_3O_4/SO_3H@zeolite-Y



R: H, 3-OCH_3, 3-OH, 4-OCH_3, 3-F, 3-NO_2, 2,3-Cl, 2,4-Cl, 4-$N(CH_3)_2$, 4-Cl, 2-NO_2, 4-CHO, 2-F, 4-CH_3

15 Examples
Yield: 50-95%
Time: 3-15 min

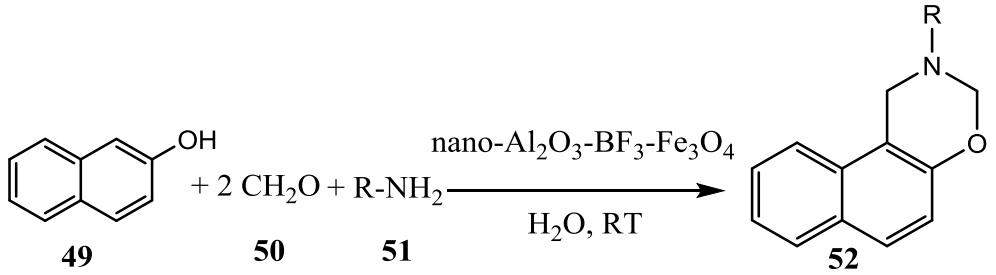
Scheme 16. Synthesis of hexahydroquinoline derivatives using Fe_3O_4-SiO_2-SiPr-HMTA-Cu

In 2019, Babaei and Mirjalili reported a one-pot synthesis of 1,3-oxazine derivatives **52** using nano-Al_2O_3-BF_3-Fe_3O_4 as reusable nanocatalyst in water at room temperature (**Scheme 17**) [27]. To synthesize 1,3-oxazine derivatives **52**, they mixed 1 mmol of *β*-naphthol **49**, 1 mmol of primary amine **50**, and 2.5 mmol of formaldehyde 37% **51** in 1.5 mL of water in the presence of 0.04 g of nano-Al_2O_3-BF_3-Fe_3O_4. All of the 2-aryl/alkyl-2,3-dihydro-1H-naphtho[1,2-e][1,3]oxazine derivatives **52** were obtained in good to excellent yields within 15-20 min. In addition, they investigated the reusability of the nano-Al_2O_3-BF_3-Fe_3O_4 and their results showed that the catalyst could be reused for five catalytic cycles. Furthermore, the chemical structure of the synthesized compounds was checked by ^{1}H NMR and ^{13}C NMR, FT-IR spectroscopy, and melting point. Interestingly, they compared their work with other catalysts such as ionic liquid [bmim]HSO_4 (5 mol%), and vitamin B_1 (10 mol%). Their results showed that the nano-Al_2O_3-BF_3-Fe_3O_4 was better than the other pointed catalysts.

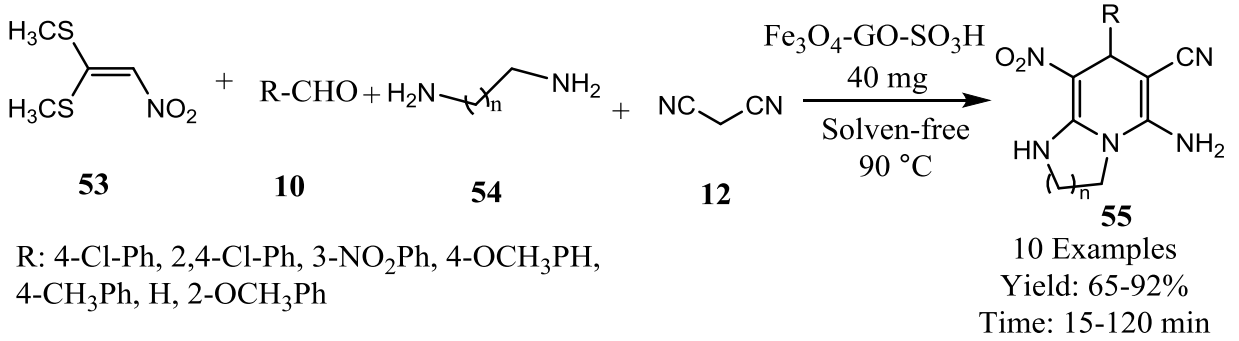
In Iran, Karimiyan and Rostamizadeh reported a green and efficient approach for the synthesis of aryl-substituted imidazo[1,2-a]pyridines and pyrido[1,2-a]pyrimidines **55** using 40 mg of Fe_3O_4-GO-SO_3H at 90 °C under solvent-free conditions (**Scheme 18**) [28]. They used the following starting materials for the production of pyrido[1,2-a]pyrimidines **55** as follows: 1,1-bis(methylthio)-2-nitroethylene **53**, aldehyde **10**, 1,n-diamine **54**, and malononitrile **12**. The final products were produced in moderate to excellent yields within 15-120 min.

In addition, the same group synthesized spiro-oxindolo-imidazo[1,2-a]pyridines and -pyrido[1,2-a] pyrimidines **57** using the same previous conditions (**Schemes 19 and 20**) [28].

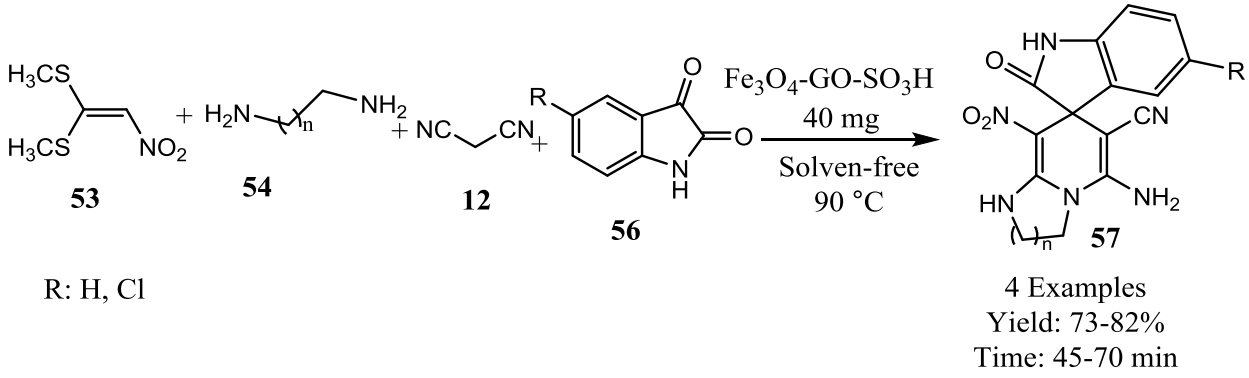
In Korea, Basavegowda and co-workers described an efficient and suitable method for the synthesis of polyfunctionalized pyridines using Fe_3O_4-MWCNTs in water under reflux conditions (**Scheme 21**) [29]. After the preparation of Fe_3O_4-MWCNTs, they characterized the pointed catalyst using XRD, FE-SEM, TEM, XPS, TGA, EDX, and VSM. Hence, 1 mmol of ketone **60**, 1 mmol of cinnamaldehyde **61**, and 3 equivalents of ammonium acetate **6** in the presence of 5.0 mg of Fe_3O_4-MWCNTs were used to synthesize polyfunctionalized pyridines **62**. The pointed catalyst showed 5 consequence catalytic cycles in 85% to 83% yields.



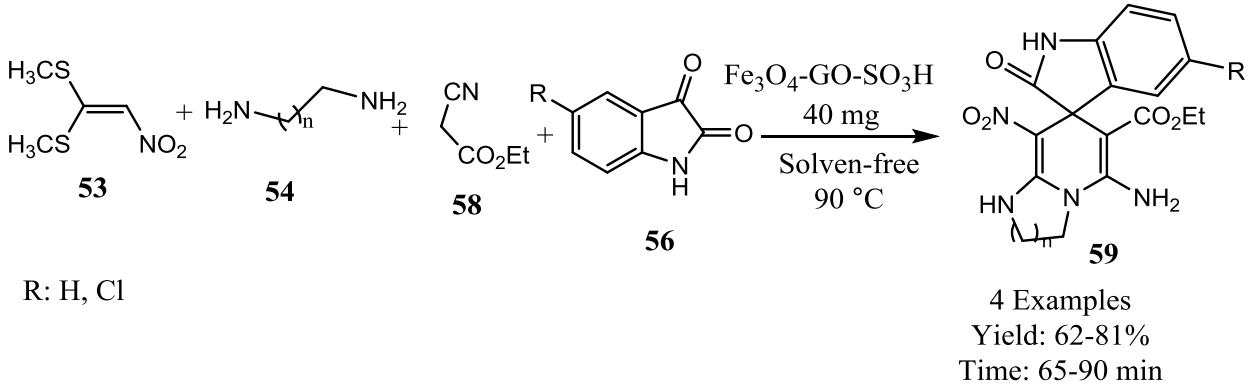
Scheme 17. Synthesis of 2-aryl/alkyl-2,3-dihydro-1H-naphtho[1,2-e][1,3]oxazine derivatives using nano-Al_2O_3-BF_3-Fe_3O_4



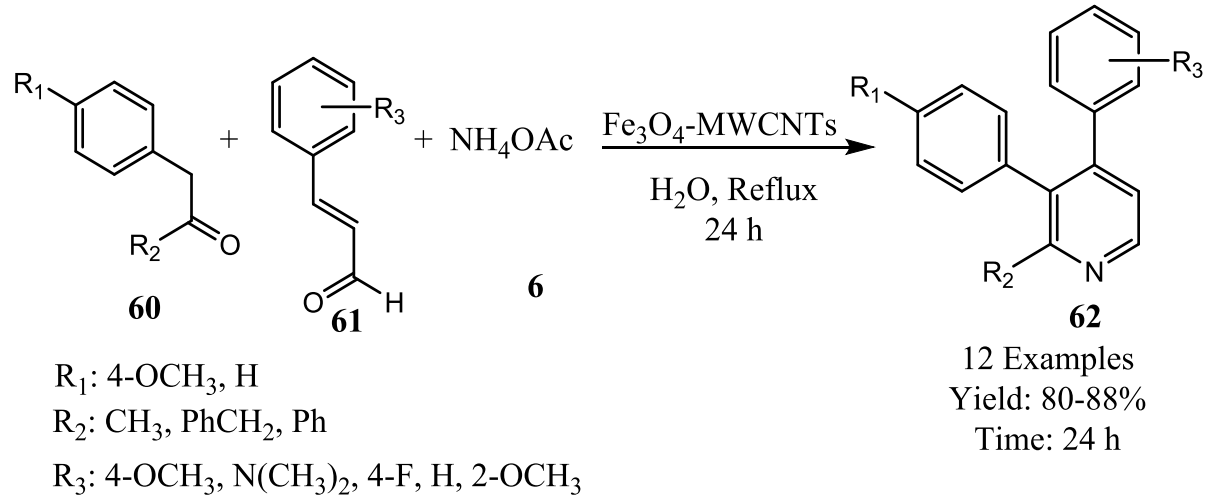
Scheme 18. Synthesis of pyrido[1,2-a]pyrimidines using Fe_3O_4-GO-SO_3H



Scheme 19. Synthesis of spiro-oxindolo-imidazo[1,2-a]pyridines and -pyrido[1,2-a] pyrimidines using Fe_3O_4-GO-SO_3H



Scheme 20. Synthesis of spiro-oxindolo-imidazo[1,2-a]pyridines and -pyrido[1,2-a]pyrimidines using Fe_3O_4-GO-SO_3H

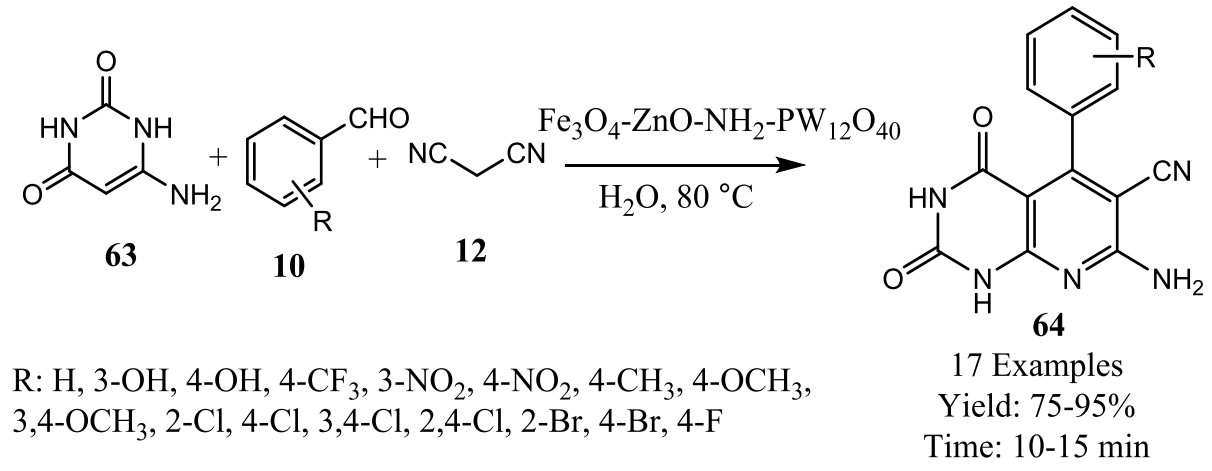


Scheme 21. Synthesis of polyfunctionalized pyridines using Fe_3O_4-MWCNTs nanocomposites

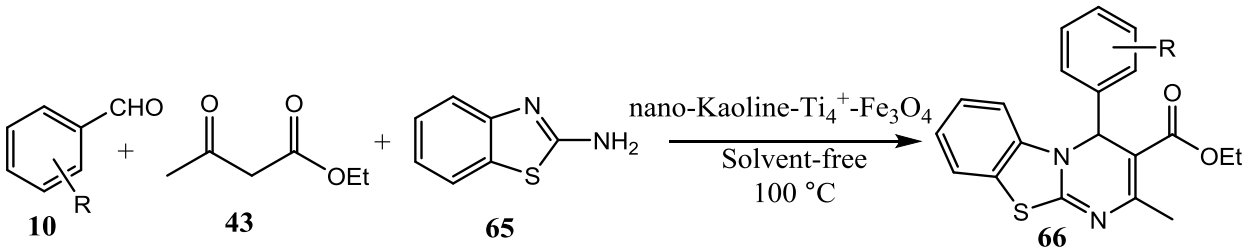
In 2019, Farokhian and co-workers reported an efficient method for the synthesis of pyrido[2,3-*d*]pyrimidine derivatives **64** using Fe_3O_4-ZnO-NH_2-$PW_{12}O_{40}$ at 80 °C in water (**Scheme 22**) [30]. The catalyst was characterized by FT-IR, XRD, VSM, SEM, EDX, and TEM analysis.

Mirjalili and Soltani developed a new method for the synthesis of pyrimido[2,1-b] benzothiazoles **66** using 1 mmol of aryl aldehydes **10**, 1 mmol of ethyl acetoacetate **43**, and 1 mmol of 2-aminobenzothiazole **65** in the presence of 0.03 g nano-Kaoline-Ti^{4+}-Fe_3O_4 at 100 °C under solvent-free conditions (**Scheme 23**) [31]. They characterized the nano-Kaoline-Ti^{4+}-Fe_3O_4 by use of FE-SEM, TEM, XRD, EDX, VSM, and TGA techniques. The pointed catalyst could be reused for 7 catalytic cycles without loss of their catalytic activity.

In 2018, Amorllahi and Vahidnia reported the synthesis of 2,3-dihydro-1H-perimidine derivatives **67** using a new heterogeneous nanocatalyst naming decoration of β-CD-ZrO supported on Fe_3O_4 nanoparticles (**Scheme 24**) [32]. The Fe_3O_4-@β-CD-ZrO nano-catalyst showed reusability for the continuous catalytic cycles. They used 1,8-diaminonaphthalene **25** in the treatment of different aromatic aldehydes **10** in the presence of Fe_3O_4-@β-CD-ZrO to produce 2,3-dihydro-1H-perimidine derivatives. The schematic representation of the prepared catalyst was shown in **Fig. 7**. In this study, for the characterization of Fe_3O_4-@β-CD-ZrO, the authors applied different techniques including TGA, XRD, SEM, TEM, and FT-IR techniques. The presented methodology has several worthwhile advantages including easy separation of the final product from the catalyst, reusability of the catalyst, high yields of the final products, and green solvent of the reaction.



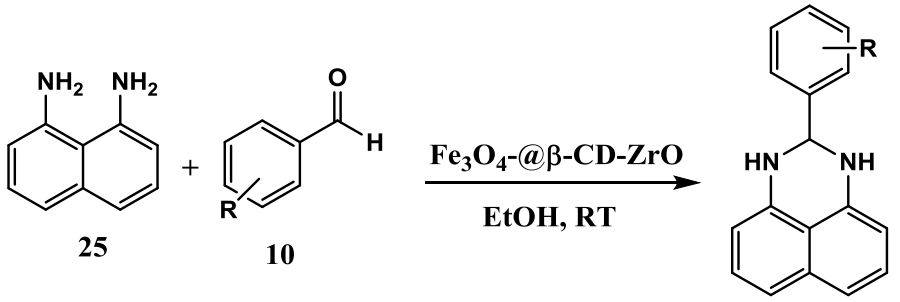
Scheme 22. Synthesis of pyrido[2,3-*d*]pyrimidine derivatives using Fe_3O_4-ZnO-NH_2-$PW_{12}O_{40}$



R: H, 4-NO_2, 4-Cl, 4-Br, 4-OH, 2-NO_2, 2-Cl, 3-NO_2, 3-OH, 2,4-Cl, 2-OCH_3, 3,4-OH

12 Examples
Yield: 50-95%
Time: 0.5-3.0 h

Scheme 23. Synthesis of pyrimido[2,1-b] benzothiazoles using nano-Kaoline-Ti^{4+}-Fe_3O_4



R: H, 4-OH, 3-OH, 2-OH, 4-OCH_3, 4-CH_3, 4-NO_2, 4-F, 2-F, 4-Cl, 2,4-Di-Cl

11 Examples
Yield: 75-90%
Time: 15-20 min

Scheme 24. Synthesis of 2,3-dihydro-1H-perimidine derivatives using Fe_3O_4-@β-CD-ZrO

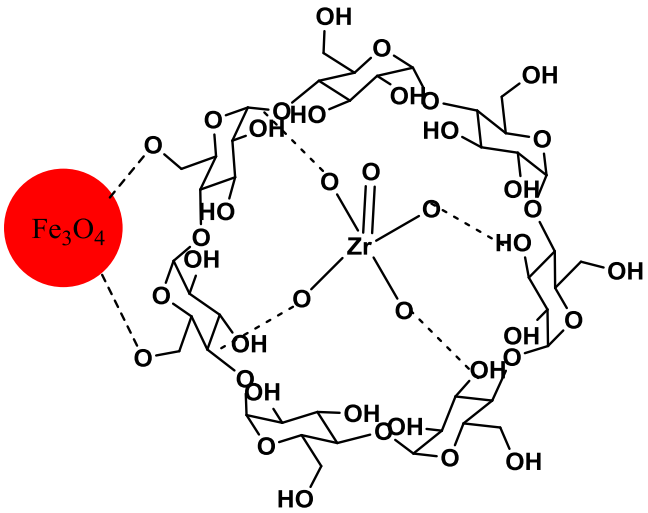


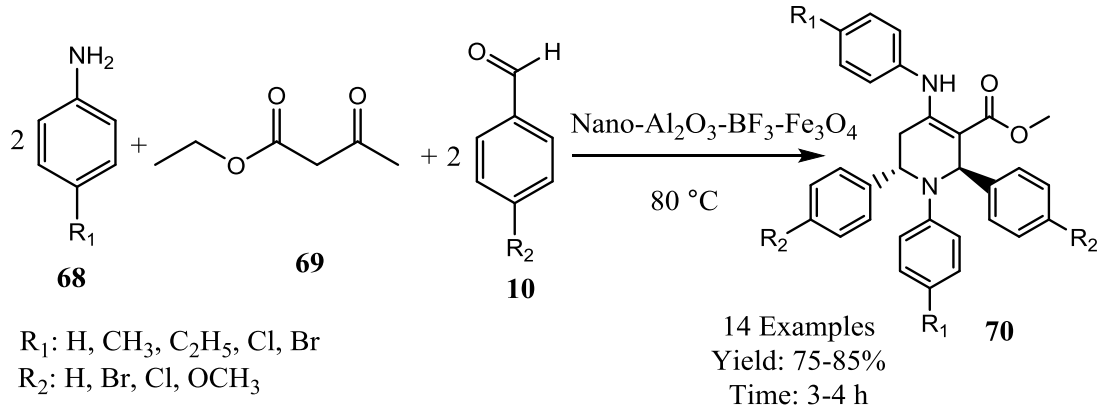
Fig. 7. The schematic representation of Fe_3O_4-@β-CD-ZrO

In a separate study, Babaei and Mirjalili introduced a one-pot method for the synthesis of tetrahydropyridines **70** using nano Al_2O_3-BF_3-Fe_3O_4 (**Scheme 25**) [33]. They characterized the prepared nanocatalyst using TEM, VSM, XRD, XRF, BET, FESEM, and FT-IR spectroscopy. They used 2 mmol of aniline derivatives **68** and 1 mmol of ethyl acetoacetate **69** in the presence of 0.03 g of Al_2O_3-BF_3-Fe_3O_4 for 3-4 h at 80 °C under solvent-free conditions. They prepared the Al_2O_3-BF_3-Fe_3O_4 as follows procedure. 1.0 g of γ-Al_2O_3, and 10 mL of dichloromethane were mixed and 0.5 mL of BF_3 was added drop-wise. In this step, the nano- Al_2O_3-BF_3 was obtained. Finally, for the synthesis of Al_2O_3-BF_3-Fe_3O_4, 1.0 g of nano- Al_2O_3-BF_3 was added to 1.0 g of Fe_3O_4 nanoparticles in 20 mL of dichloromethane and stirred for 1 h. They compared the prepared catalyst with other catalysts such as $ZrCl_4$, $ZrOCl_2.8H_2O$, $Fe(NO_3)_3.9H_2O$, $FeCl_3/SiO_2$ nanoparticles, acetic acid, CAN, PTSA, and L-proline/THF. Their results show that the nano Al_2O_3-BF_3-Fe_3O_4 was superior in terms of yield and time of the reaction.

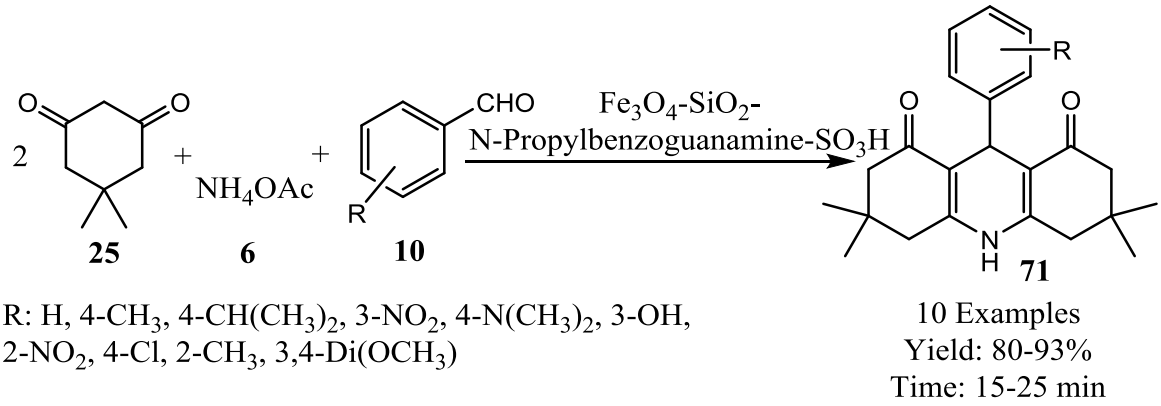
Dehbalaei and co-workers reported a novel method for the synthesis of 1,8-dioxo-decahydroacridine derivatives **71** using Fe_3O_4-SiO_2-*N*-propylbenzoguanamine-SO_3H nanocomposite (**Schemes 26** and **27**) [34]. For the preparation of 1,8-dioxo-decahydroacridine derivatives **71** using Fe_3O_4-SiO_2-*N*-propylbenzoguanamine-SO_3H nanocomposite, 2 mmol of dimedone **25**, 1 mmol of aromatic aldehydes **10**, and 1.2 mmol of ammonium acetate **6** or aniline **68** were added to 2.0 mL of (H_2O: EtOH 1:3) as a solvent in the presence of 6.0 mg of Fe_3O_4-SiO_2-*N*-propylbenzoguanamine-SO_3H at 100 °C for the appropriate time. In this study, the prepared catalyst was identified using FT-IR, FESEM, EDXA, XRD, VSA,

ICP-MS, and TGA techniques. The obtained tests show that the average size of Fe_3O_4-SiO_2-*N*-propylbenzoguanamine-SO_3H was approximately 25 nm. The schematic representation of Fe_3O_4-SiO_2-*N*-propylbenzoguanamine-SO_3H was shown in **Fig. 8**.

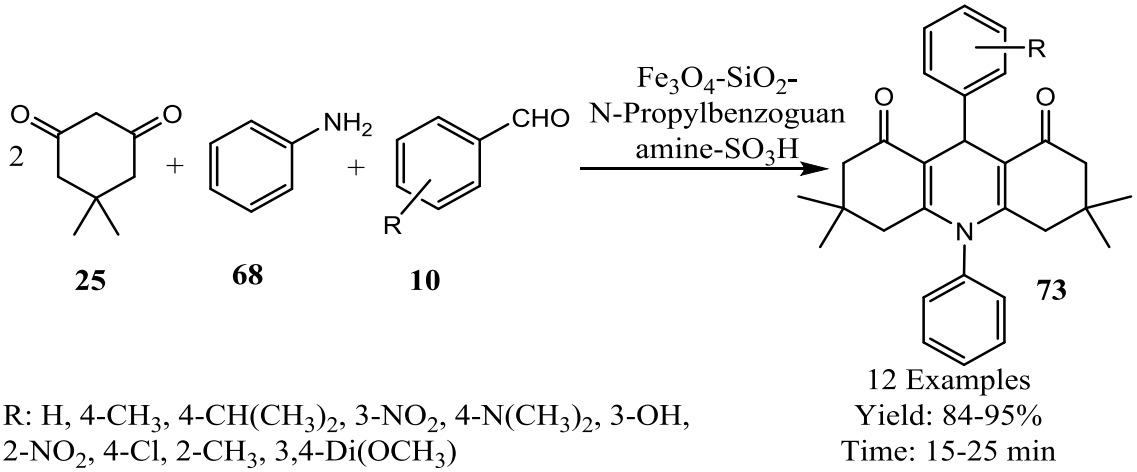
In 2018, Hazeri and co-workers reported a diastereoselective synthesis of fully functionalized tetrahydropyridines **75** using Fe_3O_4-SiO_2-TiO_2 nanocomposites at 50 °C in ethanol as a green solvent (**Scheme 28**) [35]. They used 2.0 mmol of aromatic amines **68**, 1.0 mmol of *β*-ketoester **74**, and 2.0 mmol of aromatic aldehydes **10** in the presence of 2 mol% of Fe_3O_4-SiO_2-TiO_2 nanocomposites at 50 °C for an appropriate time. The synthesized compounds were identified using ^{1}H NMR and melting point. The Fe_3O_4-SiO_2-TiO_2 nanocomposites show reusability for 4th runs catalytic cycles without loss of their catalytic activity.



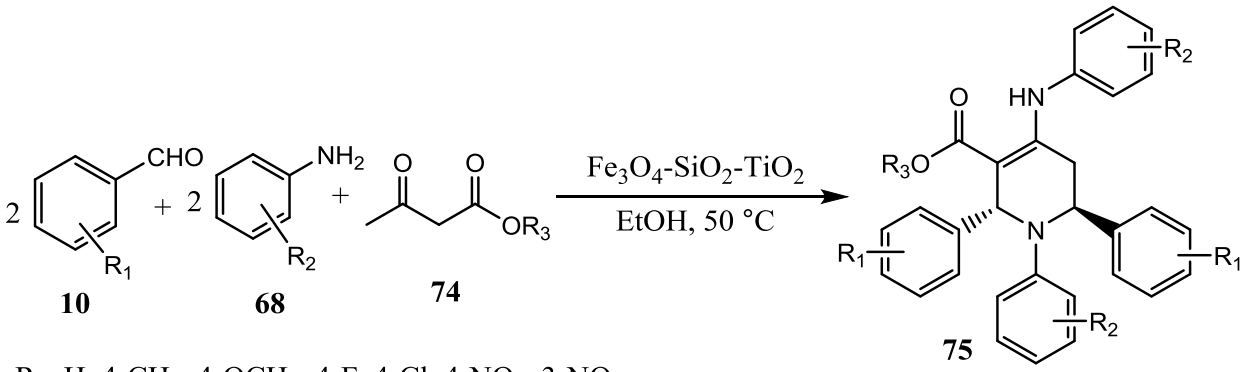
Scheme 25. Synthesis of tetrahydropyridines using nano Al_2O_3-BF_3-Fe_3O_4



Scheme 26. Synthesis of 1,8-dioxo-decahydroacridine derivatives using Fe_3O_4-SiO_2-*N*-propylbenzoguanamine-SO_3H nanocomposite



Scheme 27. Synthesis of 1,8-dioxo-decahydroacridine derivatives using Fe_3O_4-SiO_2-*N*-propylbenzoguanamine-SO_3H nanocomposite



R_1: H. 4-CH_3, 4-OCH_3, 4-F, 4-Cl, 4-NO_2, 3-NO_2

R_2: H, 4-OCH_3, 4-Cl, 4-Br, 4-CH_3, 4-F

R_3: Me, Et

18 Examples
Yield: 50-88%
Time: N. A.

Scheme 28. Diastereoselective synthesis of fully functionalized tetrahydropyridines using Fe_3O_4-SiO_2-TiO_2 nanocomposites

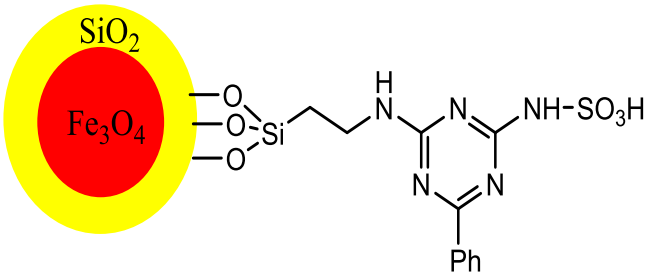
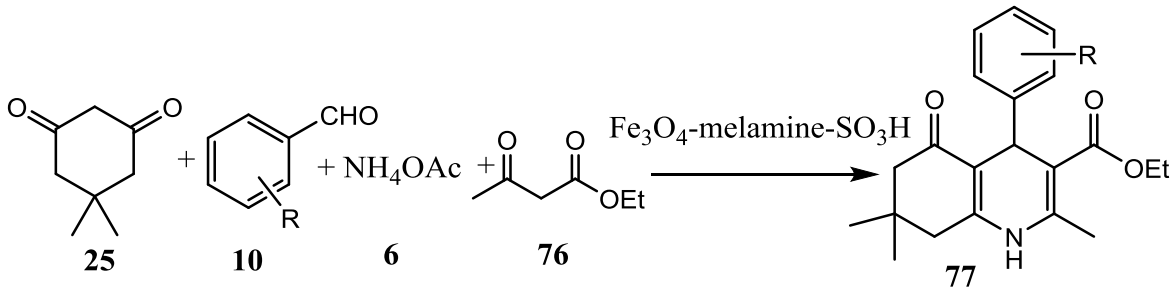


Fig. 8. The representation of the chemical structure of Fe_3O_4-SiO_2-*N*-propylbenzoguanamine-SO_3H nanocomposite

In 2018, Khazaei and co-workers designed a new catalyst for the synthesis of hexahydroquinoline derivatives **77** (**Scheme 29**) [36]. The chemical structure of Fe_3O_4-melamine-SO_3H was shown in **Fig. 9**. The total density of sulfonic acid groups anchored on Fe_3O_4-melamine has been calculated at approximately 6.6 mmol of H^+/g. The pointed catalyst was characterized using FT-IR, XRD, EDX, TEM, SEM, TGA, and VSM techniques. Interestingly, they proposed the mechanism of the reaction using FT-IR spectroscopy. In addition, the Fe_3O_4-melamine-SO_3H show good reusability for 4 catalytic cycles. The metal-free, solvent-free, green chemistry and simple separation of the catalyst are other advantages of the presented method.

In 2018, Mirjalili and Aref reported nano-cellulose-BF_3-Fe_3O_4 as a bio-magnetic nanocatalyst for the synthesis of pyrimido[2,1-b]benzothiazoles **80** under solvent-free conditions (**Scheme 30**) [37]. The authors synthesized nano-cellulose from cotton. To prepare pyrimido[2,1-b]benzothiazoles, 0.06 g of nano-cellulose-BF_3-Fe_3O_4 was added to 1.0 mmol of ethyl acetoacetate **78**, 1.0 mmol of aromatic aldehyde **10**, and 1.0 mmol of 2-aminobenzothiazole **79** at 100 °C for the appropriate time. Moreover, the catalyst recycling tests were performed and displayed 4 catalytic cycles without loss of their catalytic activity.



R: H, 2-NO_2, 4-Br, 4-$N(CH_3)_2$, 3-F, 2,4-Cl, 4-Cl, 3-OH, 4-CH_3, 2-Cl, 2-OCH_3, 2,3-Cl, 3-OCH_3, 2-F, naphthaldehyde, thiophene

16 Examples
Yield: 48-90%
Time: 4-11 min

Scheme 29. Synthesis of hexahydroquinoline derivatives using Fe_3O_4-melamine-SO_3H

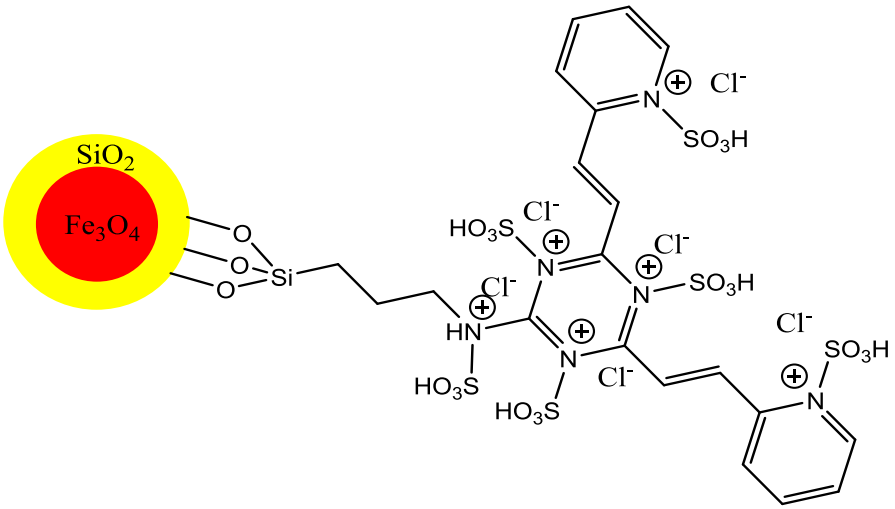
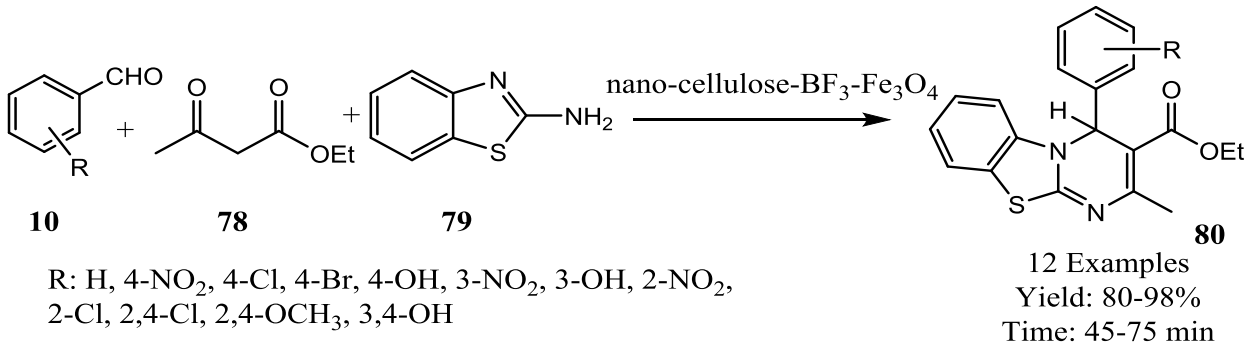
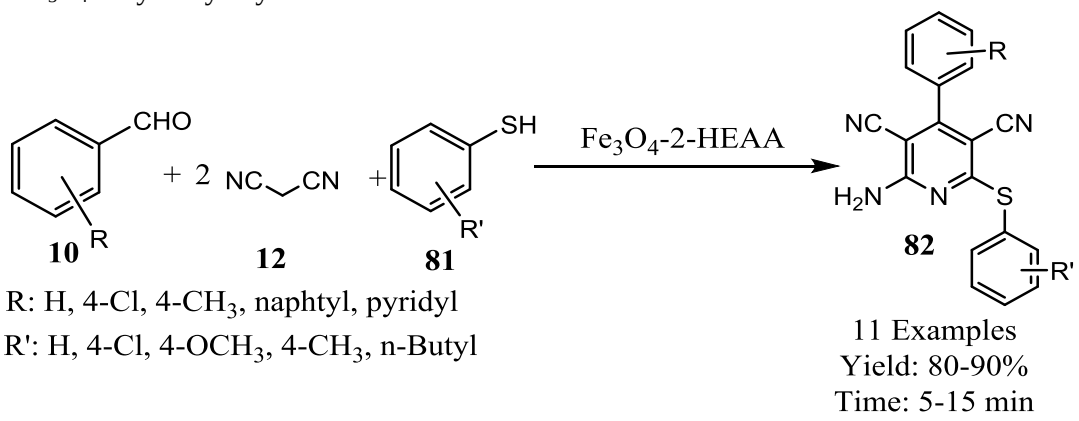


Fig. 9. The schematic representation of Fe_3O_4-melamine-SO_3H



Scheme 30. Synthesis of pyrimido[2,1-b]benzothiazoles using nano-cellulose-BF_3-Fe_3O_4 under solvent-free conditions

In 2018, Sobhani and co-workers developed a novel method for the synthesis of pyridine derivatives **82** using Fe_3O_4-2-hydroxyethylammonium acetate (HEAA) (**Scheme 31**) [38]. The schematic representation of Fe_3O_4-2-HEAA was shown in **Fig. 10**. For the preparation of 2-amino-3,5-dicarbonitrile-6-thio-pyridines in the presence of Fe_3O_4-2-hydroxyethylammonium acetate (HEAA) (0.016 g or 1.0 mol%), 2.0 mmol of malononitrile **12**, 1.0 mmol of aromatic aldehyde **10**, and 1.0 mmol of thiol derivatives **81** were heated at 70 °C. The final product was identified using ^{1}H NMR, FT-IR, and melting point. The Fe_3O_4-2-hydroxyethylammonium acetate was characterized using FT-IR, XRD, SEM, TEM, and TGA analysis.



Scheme 31. Synthesis of 2-amino-3,5-dicarbonitrile-6-thio-pyridines in the presence of Fe_3O_4-2-hydroxyethylammonium acetate (HEAA)

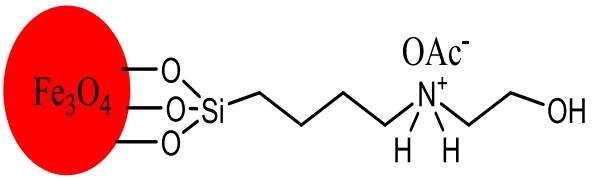


Fig. 10. The chemical structure of Fe_3O_4-2-hydroxyethylammonium acetate (HEAA)

In 2017, Abdi and co-workers reported a green and efficient method for the synthesis of 1'Hspiro[isoindoline-1,2'-quinazolie]3,4'(3'H)dione derivatives **86** in the presence of Fe_3O_4-graphene oxide-SO_3H at 120 °C under solvent-free conditions (**Scheme 32**) [39]. They used 1.4 mmol of isatoic anhydride **83**, 1.0 mmol of isatin **85**, 1.5 mmol of primary amine **84** using 1.0 g of Fe_3O_4-graphene oxide-SO_3H at 120 °C under solvent-free conditions. The 1'Hspiro [isoindoline-1, 2'-quinazolie] 3, 4' (3'H)dione derivatives were identified using ^1H NMR, ^{13}C NMR, CHNS, and melting point. In addition, the Fe_3O_4-graphene oxide-SO_3H was characterized by TEM, SEM, FT-IT, EDX, XRD, and TGA analysis. The reusability of the catalyst for 4 runs, short reaction times, and high yields of the products were some of the advantages of the current methodology.

In 2017, Beyki and Fallah-Mehrjerdi reported a powerful method for the synthesis of 2,3-dihydroquinazolin-4(1H)-ones **89** using Fe_3O_4-SiO_2-SO_3H at room temperature under solvent-free conditions (**Scheme 33**) [40]. The chemical structure of Fe_3O_4-SiO_2-SO_3H was shown in **Fig. 11**. In the current research, 0.05 g of Fe_3O_4-SiO_2-SO_3H was added to the 1.0 mmol of anthralinamide **87** and 1.0 mmol of aldehydes or ketones **88** for the appropriate time. The prepared catalyst was characterized using FT-IR, SEM, EDX, and XRD analysis. The authors compared the prepared catalyst with other reported catalysts such as $Ga(OTf)_3$, $Sc(OTf)_3$, NH_4Cl, $H_3PW_{12}O_{40}$, $SiCl_2.6H_2O$, $ZrCl_4$, and $Y(OTf)_2$. Their comparison shows that the Fe_3O_4-SiO_2-SO_3H nanocatalyst was superior in terms of the time of the reaction and yield of the final product.

In Taiwan, in 2017, Dam and co-workers reported an efficient and novel method for the preparation of dihydroquinazolinone derivatives **94** using Fe_3O_4-DOPA(dopamine)-SnO_2 nanocatalyst at 80 °C in water (**Scheme 34**) [41]. To synthesize dihydroquinazolinone derivatives **94**, 1.0 mmol of isatoic anhydride **90**, 1.5 mmol of ammonium acetate **92**, and 1.0 mmol of amine derivatives **91** in the presence of 10 mg of Fe_3O_4-DOPA-SnO_2 nanocatalyst in 5.0 mL of water were heated at 80 °C. The Fe_3O_4-DOPA-SnO_2 nanocatalyst was characterized by FT-IR, TEM, HRTEM, SEM, EDX, XPS, XRD, VSM, and TGA analysis. Good to excellent yield, relatively reaction times, green solvent, and reusability of the catalyst for 5 catalytic cycles are some of the advantages of the presented method.

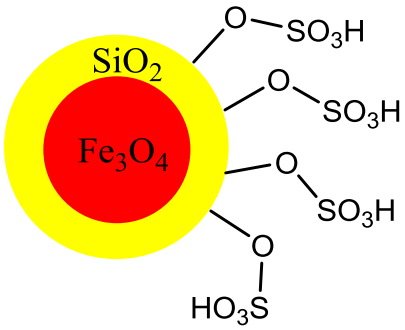
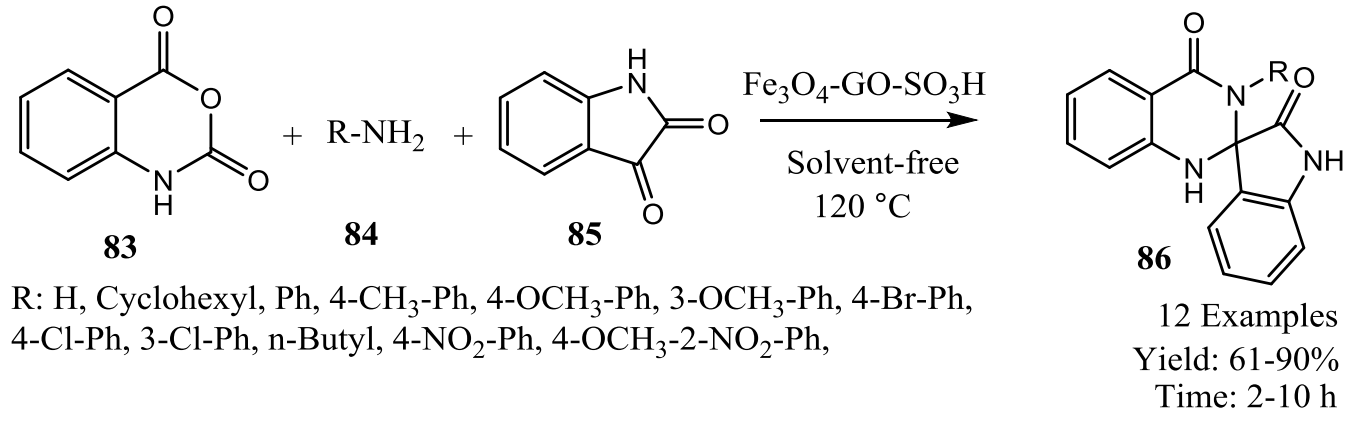
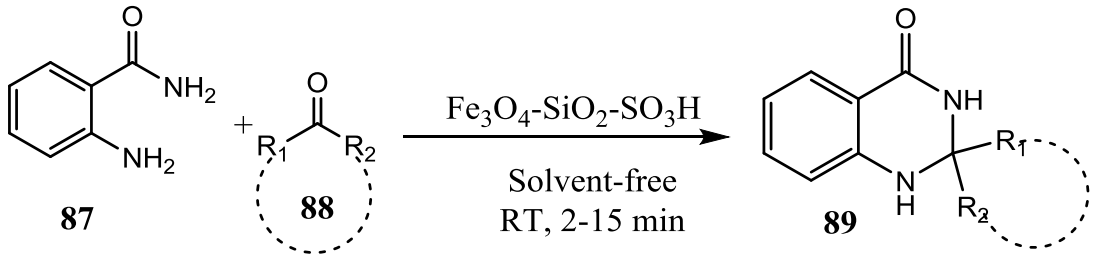


Fig. 11. The schematic representation of Fe_3O_4-SiO_2-SO_3H



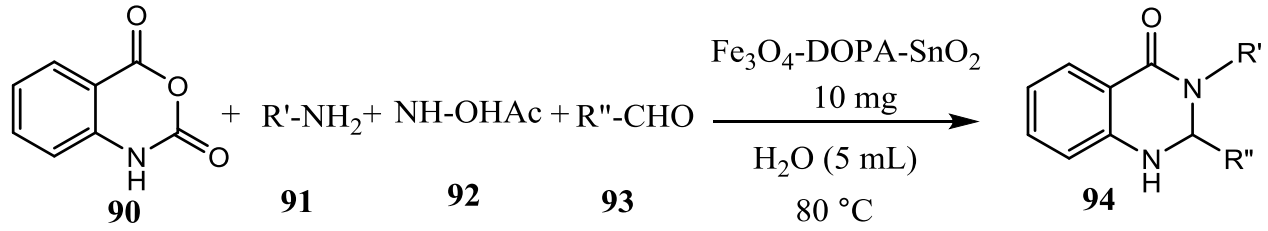
Scheme 32. Synthesis of 1'Hspiro [isoindoline-1, 2'-quinazolie] 3, 4' (3'H)dione derivatives using Fe_3O_4-graphene oxide-SO_3H



A: Benzaldehyde (a); 4-CH_3-a; 4-OCH_3-a; 2-OH-a; 2-Cl-a; 3-Cl-a; 4-Cl-a; 3-NO_2-a; 2,5-DiOCH_3-a; 3,4-DiOH-a; 4-Dimethylamino-a; Cinnamaldehyde; 2-Furaldehyde; Cyclopentanone(hexanone) (heptanone); Isatin; 1,4-Cyclohexandione

19 Examples
Yield: 82-96%
Time: 2-15 min

Scheme 33. Synthesis of 2,3-dihydroquinazolin-4(1H)-ones using Fe_3O_4-SiO_2-SO_3H



R': 4-methylphenyl; benzimidazole

R": 4-Cl, 4-CN, 4-Br, 4-OCH_3, 4-CH_3, 2-NO_2, 2-CH_3, H, 2-OCH_3-PhCHO, aliphatic aldehyde, tricyclic aldehyde

16 Examples
Yield: 82-92%
Time: 45-90 min

Scheme 34. Preparation of dihydroquinazolinone derivatives using Fe_3O_4-DOPA(dopamine)-SnO_2 nanocatalyst

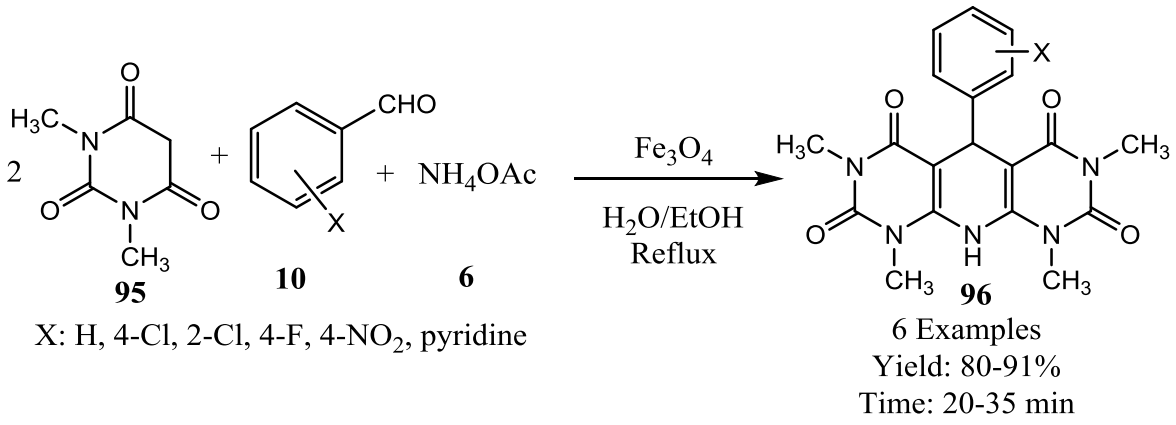
In 2017, Fattahi and co-workers reported a one-pot and efficient synthesis of novel pyrimido[5',4':5,6]pyrido[2,3-d]pyrimidines **96** catalyzed by magnetic iron oxide nanoparticles (**Scheme 35**) [42]. They reacted 2.0 mmol of 1,3-dimethylbarbituric acid **95**, 1.0 mmol of aromatic aldehydes **10**, and 1.2 mmol of ammonium acetate **6** in the presence of 0.075 g of Fe_3O_4 nanoparticles in 5 mL of ethanol: water (1:1). The obtained products were approved using ^{13}C NMR, ^{1}H NMR, FT-IR, and melting point.

In 2017, Mirjalili and Tafti developed a novel method for the synthesis of quinoxaline derivatives **99** using nano-Kaoline-BF_3-Fe_3O_4 nanocomposite in grinding conditions (**Scheme 36**) [43]. The final products were identified using ^{1}H NMR, ^{13}C NMR, FT-IR, and melting point. In addition, the nano-Kaoline-BF_3-Fe_3O_4 nanocomposite was characterized using FT-IR, SEM, EDX, TEM, VSM, TGA, BET, and XRD analysis.

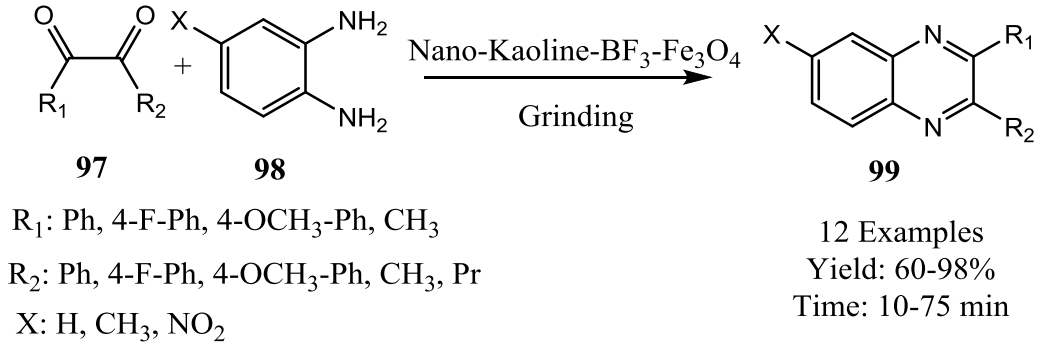
In 2017, Naeimi and Lahouti developed a one-pot synthesis of spiroacridines **102** using Fe_3O_4-CS-SO_3H under ultrasound irradiation (**Scheme 37**) [44]. In this three-component and one-pot reaction, a mixture of acenaphthoquinone **101**, dimedone **25**, and different anilines **100** were used in the presence of Fe_3O_4-CS-SO_3H in ethanol: water under ultrasound irradiation. They characterized the Fe_3O_4-CS-SO_3H using XRD, VSM, SEM, FT-IR, and EDX techniques. They found that in comparison with conventional methods, ultrasound irradiation has several worthwhile advantages including the high yield of final products, short reaction times, and reusability of the catalyst.

In China, Zhang and co-workers designed a new ionic liquid supported on Fe_3O_4 nanoparticles for the synthesis of polyhydroquinolines **105** at 70 °C under solvent-free conditions (**Scheme 38**) [45]. The prepared catalyst was characterized using XRD, TGA, FT-IR, TEM, and VSM analysis. The Fe_3O_4-SiO_2-BIL shows the reusability for six catalytic cycles without loss of their catalytic activity.

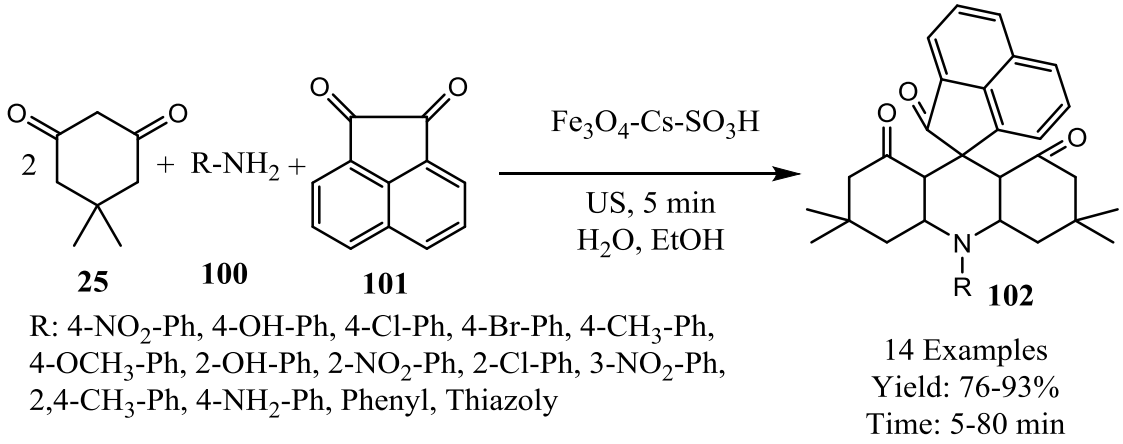
This group also checked the synthesis of Knoevenagel condensation of aromatic aldehydes with malonitrile derivatives (**Scheme 39**). The schematic representation of the prepared catalyst was shown in **Fig. 12**.



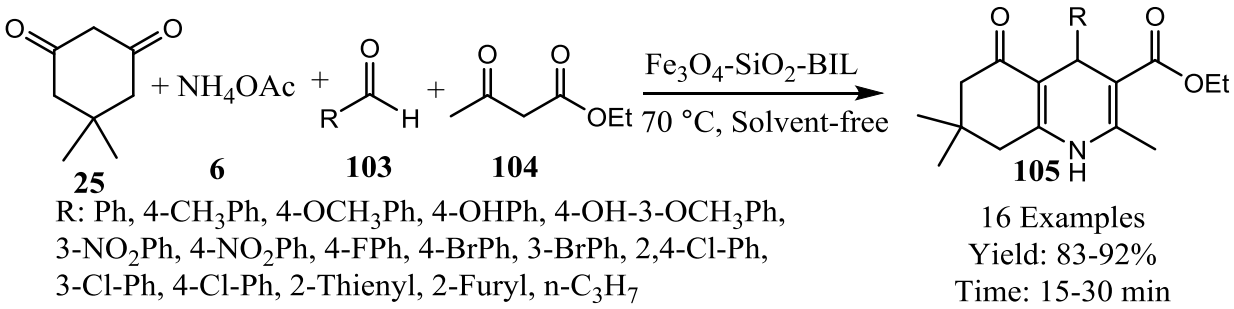
Scheme 35. Synthesis of pyrimido[5',4':5,6]pyrido[2,3-d]pyrimidines using Fe_3O_4 nanoparticles



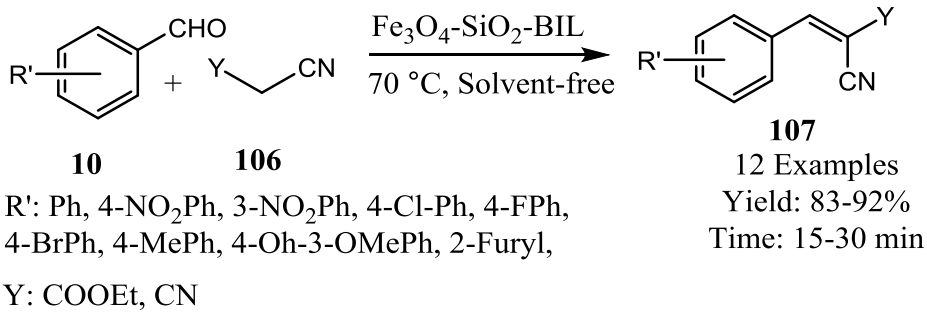
Scheme 36. Synthesis of quinoxaline derivatives using nano-Kaoline-BF_3-Fe_3O_4 nanocomposite



Scheme 37. One-pot synthesis of spiroacridines using Fe_3O_4-CS-SO_3H under ultrasound irradiation



Scheme 38. Synthesis of polyhydroquinolines using Fe_3O_4-SiO_2-BIL



Scheme 39. The Knoevenagel condensation by Fe_3O_4-SiO_2-BIL

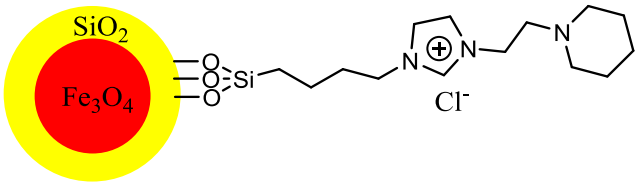


Fig. 12. The chemical structure of Fe_3O_4-SiO_2-BIL

There is a lot of review paper concerning heterocyclic compounds in the research database. But the six-membered heterocyclic compounds containing nitrogen atom has grown into a wide subject area in recent years. The main limitation of this review paper was focusing on nitrogen atom compounds while a lot of heterocyclic compounds with other atoms such as oxygen, and sulfur are in natural and drug compounds. The strength of this review paper is the discussion of the 6-membered ring compounds containing the nitrogen atom catalyzed by magnetically heterogeneous nanocatalysts based on Fe_3O_4 nanoparticles.

4. Conclusions

In conclusion, a comprehensive review of the catalytic methods was developed for the synthesis of six-membered compounds (heterocyclic compounds) containing nitrogen catalyzed by functionalized Fe_3O_4 nanoparticles. The application of these catalytic systems in the synthesis of different organic reactions such as cyclization, condensation, ring-opening, and addition reactions have been investigated in the presence of functionalized Fe_3O_4 nanoparticles. In addition, it is described in all of the reactions, that the magnetic catalytic systems could be separated by the use of the external magnet. Notably, in all of the reactions, a new carbon-nitrogen bond was formed to form six-membered organic compounds.

Authors Contributions

Faris H. Mohammed proposed the idea, searched databases, downloaded PDFs, extracted data, and wrote the draft. Aseel M. Aljeboree proposed the idea, searched databases, downloaded PDFs, and extracted data. Alrazzak Nour Abd was the head of the group and rewrote the final draft and submission. Ayad F. Alkaim extracted data and drew the chemical compounds. Yasir Salam Karim extracted data and drew the chemical compounds. Sarah A. Hamood revised English and revised based on the editors' comments. Ahmed B. Mahdi and Mohammed Abed Jawad proposed the idea, searched the databases, and downloaded PDFs. Salam Ahjel extracted data.

Competing Interests: The authors declare no competing interests.

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