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Nanoporous TiO_2 containing an ionic liquid bridge as an efficient and reusable catalyst for the synthesis of *N*,*N*′-diarylformamidines, benzoxazoles, benzothiazoles and benzimidazoles†

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In this work, a green and efficient procedure is reported for the preparation of *N*,*N*′-diarylformamidines, benzoxazoles, benzothiazoles, and benzimidazoles using nanoporous TiO_2 containing an ionic liquid bridge. This reagent is prepared *via* the modification of nanoporous TiO_2 with bis-3-(trimethoxysilylpropyl)-ammonium hydrogen sulfate (TiO_2-[bip]-NH_2^+ HSO_4^-). The procedure gave the products in excellent yields in very short reaction times under solvent-free conditions. The reusability of the catalyst is the other important feature of the reported method.

Introduction

Formamidines are one of the important intermediates for the preparation of heterocyclic and functional group transformations.[1] In addition, these compounds have many biological and pharmaceutical properties including antimicrobial, antiviral and anti-hypertension activities.[2,3] Also, they have been employed as protecting groups for primary amines and as building blocks in polymer synthesis.[4,5] On the other hand, *N*,*N*′-diarylformamidines (ArN = CHNHAr) and their anions have been widely used in coordination chemistry by coordination with metal centers to form chelating, bridging and chelating/bridging bonding modes.[6–8] The general procedure for the synthesis of formamidines involves the reaction between two moles of aniline derivatives and one mole of ethyl orthoformate in the presence of an acidic catalyst.[9–11]

Benzimidazole, benzoxazole, benzothiazole and their derivatives are important classes of heterocyclic compounds showing considerable biological properties. They are important intermediates for the synthesis of some drugs, for example a benzimidazole framework exists in the structure of vitamin B_{12}.[12] Furthermore, these heterocyclic compounds can be extensively used as ligands for transition metals.[13]

Condensation of *o*-aminobenzenethiol, *o*-aminophenol or *o*-phenylenediamine with acid chlorides,[14] carboxylic acids,[15,16] esters,[17] aldehydes,[18–25] nitrile oxide,[26] dibromomethylarenes[27] and *ortho* esters[28–34] in the presence of a strong acid is one of the methods that has been used for the synthesis of these derivatives.

Despite the improved methods, each of them suffer from disadvantages such as long reaction times, harsh reaction conditions, need for excess amounts of reagents, use of organic solvents, use of toxic reagents, and non-recoverability of the catalyst. Due to these problems it would be interesting to provide a simple and effective method for the synthesis of these compounds.

In the last few decades, immobilized ionic liquids have become attractive because the immobilization of ionic liquids on solid surfaces is a useful method for the preparation of solid and heterogeneous catalysts. These types of catalysts retain the benefits of ionic liquids, including excellent flexibility, heat resistance, non-volatility, non-corrosiveness, slight vapor pressure and tunable polarity with common organic solvents.[35] Furthermore, the immobilization of ionic liquids removes some defects, such as improving the recovery and reusability of the catalyst and decreasing the amount of IL utilized and its cost.

Among various substrates, metal oxides are one of the suitable substrates for the immobilization of ionic liquids. TiO_2 nanoparticles due to their low cost, easy synthesis and high thermal stability can efficiently be used for this purpose.[36]

In this study and in continuation of our previous reports on the preparation and application of nano catalysts in organic transformations,[37–39] nanoporous TiO_2 modified with bis-3-(trimethoxysilylpropyl)-amine is easily prepared and characterized using different techniques such as FT-IR, X-ray diffraction (XRD), field emission scanning electron microscopy (FESEM) and thermogravimetric analysis (TGA). Its application in the

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† Electronic supplementary information (ESI) available: FT-IR, ^{1}H NMR and ^{13}C NMR of the new products. See DOI: 10.1039/c8nj00171e

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synthesis of *N*,*N*′-diarylformamidines, benzoxazoles, benzothiazoles, and benzimidazoles is then studied.

Experimental

All the chemicals were purchased from Fluka, Merck, and Aldrich chemical companies. All yields refer to the isolated products. The products were characterized by comparison of their physical constants, and IR and NMR spectra with authentic samples and those reported in the literature. The purity determination of the substrate and reaction monitoring were performed by TLC on silicagel polygram SILG/UV 254 plates.

Preparation of nanoporous TiO_2

The required amount of titanium tetraisopropoxide (TTIP) (a TTIP : EtOH volume ratio of 1 : 6) was mixed with ethanol. Then, deionized water was slowly added to the resulting mixture (TTIP : water with a ratio of 1 : 60) to cause the hydrolysis of TTIP and stirring was maintained for 2 h to hydrolyze TTIP completely. The prepared material was separated by filtration, washed with water, and dried at 80 °C. Finally, the obtained solid was calcinated at 500 °C for 3 h to obtain nanoporous TiO_2.[40]

Preparation of nanoporous TiO_2 modified with bis-3-(trimethoxysilylpropyl)-ammonium hydrogen sulfate (TiO_2-[bip]-NH_2^+ HSO_4^-)

Bis-3-(trimethoxysilylpropyl)-amine (5 mmol) was added to 5 g of TiO_2 in 25 mL of ethanol and the reaction mixture was refluxed with stirring for 3 days. After cooling to room temperature, the mixture was filtered and the product was washed with 10 mL of Et_2O and dried under vacuum. Subsequently, the reaction product (6.5 g) was suspended in 20 mL of dry CH_2Cl_2. Then, under vigorous stirring in an ice bath (0 °C), 5 mmol concentrated H_2SO_4 (97%) was added dropwise to the mixture. The mixture was refluxed with stirring for 24 h. After filtration, TiO_2-[bip]-NH_2^+ HSO_4^- was obtained as a white solid (Scheme 1).

General procedure for the synthesis of *N*,*N*′diphenylformamidines

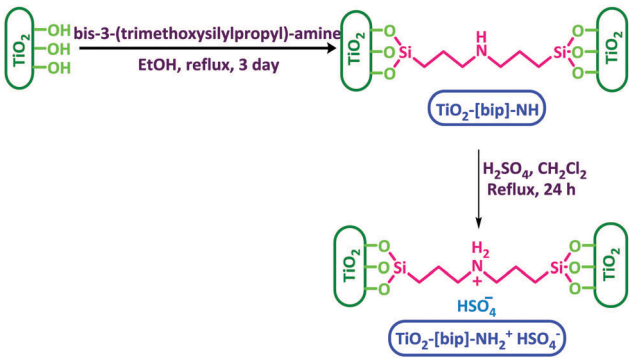
An aromatic amine (2 mmol) was added to a mixture of TiO_2-[bip]-NH_2^+ HSO_4^- (10 mg) and triethyl orthoformate (1.5 mmol), and the resulting mixture was stirred at 60 °C for the appropriate time. After completion of the reaction as indicated by TLC [EtOAc : *n*-hexane (1 : 1)], ethyl acetate (20 mL) was added and the catalyst was separated by filtration. The organic phase was washed with brine and dried over Na_2SO_4. Then the solvent was removed under reduced pressure. Subsequently, the product was purified by recrystallization from *n*-hexane to afford the desired product in good to high yields. The spectral data of the prepared new compounds are as follow:

N,*N*′-Bis(3,4-dimethoxyphenyl)formimidamide: IR (KBr) ν = 3439, 3071, 2997, 2916, 2833, 1670, 1599, 1512, 1449, 1307, 1238, 1141, 1023, 841, 799, 765 cm^{-1}; ^1H NMR (DMSO-d_6, 400 MHz) δ = 3.71 (6H, s, OCH_3), 3.76 (6H, s, OCH_3), 6.75 (2H, s), 6.86 (4H, d, J = 8), 8.09 (1H, s, CH), 9.40 (1H, s, NH) ppm; ^{13}C NMR (DMSO-d_6, 100 MHz): δ = 55.90, 59.37, 104.50, 110.68, 113.24, 144.92, 147.97, 149.70 ppm.

N,*N*′-Bis(2,6-difluorophenyl)formimidamide: IR (KBr) ν = 3403, 3019, 2936, 2887, 1667, 1582, 1482, 1314, 1210, 994, 770 cm^{-1}; ^1H NMR (DMSO-d_6, 400 MHz) δ = 7.12 (6H, s), 8.04 (1H, s, CH), 9.48 (1H, s, NH) ppm; ^{13}C NMR (DMSO-d_6, 100 MHz): δ = 112.21, 112.27, 112.38, 112.45, 123.88, 155.20, 157.65 ppm.

General procedure for the synthesis of benzimidazole, benzoxazole, and benzothiazole derivatives

1,2-Phenylenediamine, 2-aminophenol, or 2-aminothiophenol (1 mmol) was added to a mixture of TiO_2-[bip]-NH_2^+ HSO_4^- (10 mg) and the corresponding *ortho* ester (trimethyl orthoformate, triethyl orthoformate, or triethyl orthoacetate) (1.5 mmol), and the resulting mixture was stirred at 90 °C for the appropriate time. After completion of the reaction, which was monitored by TLC [EtOAc : *n*-hexane (1 : 1)], ethyl acetate (20 mL) was added and the catalyst was separated by filtration. The organic phase was washed with brine and dried over Na_2SO_4. Then, the solvent was removed under reduced pressure. If necessary the product was purified by recrystallization from *n*-hexane to afford the desired product in good to high yield.



Scheme 1 Preparation of TiO_2-[bip]-NH_2^+ HSO_4^-.

Results and discussion

Instrumentation

FT-IR spectra were recorded on a VERTEX 70 (Brucker, Germany) instrument using KBr pellets for solid samples and neat for liquid samples in the range of 4000–400 cm^{-1}. X-ray diffraction (XRD) analysis was performed on an X'Pert MPD diffractometer using Cu Kα radiation (λ: 1.78897 Å). Field Emission Scanning Electron Microscopy (FESEM) images were obtained using a TE-SCAN model MIRA3 microscope. Thermogravimetric Analysis (TGA) was performed using a TGA-DTA METTLER TGA/STTA 851 analyzer (swiss).

Catalyst characterization

The FT-IR spectra of TiO_2, TiO_2-[bip]-NH and TiO_2-[bip]-NH_2^+ HSO_4^- are compared in Fig. 1. In the spectrum of TiO_2 the peaks at 3402 and 1630 cm^{-1} are related to the hydroxyl groups of TiO_2 and adsorbed water, respectively.[41] Also, the vibration

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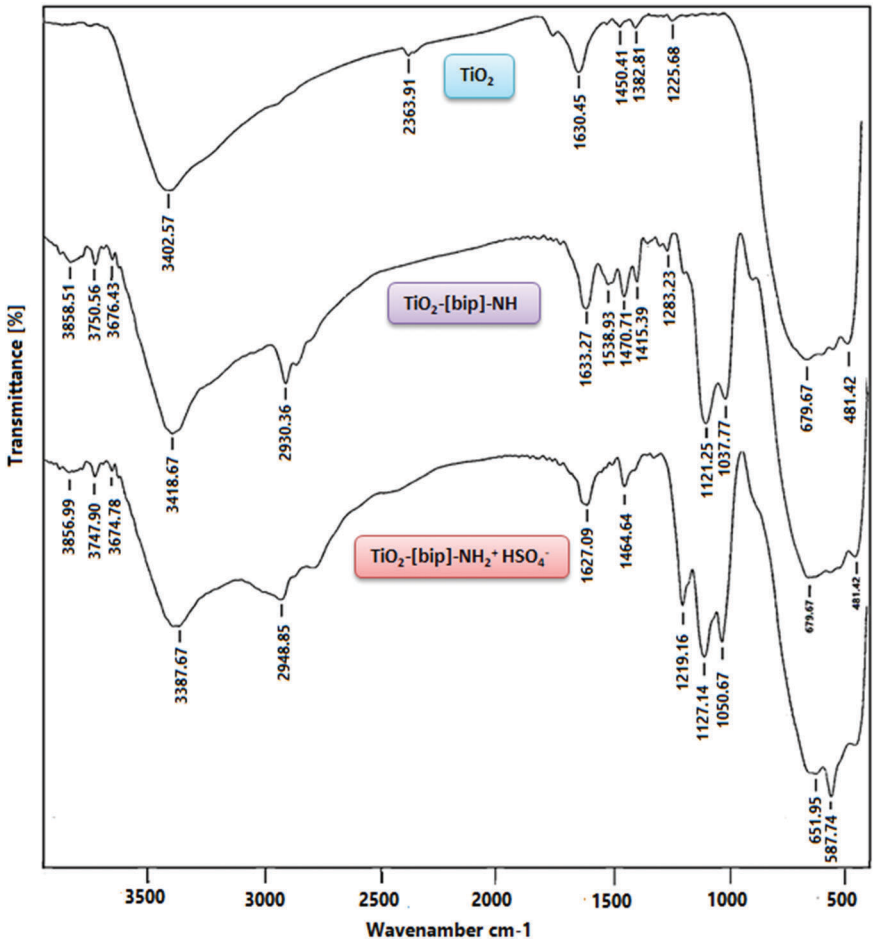

Fig. 1 FT-IR spectra of TiO_2, TiO_2-[bip]-NH and TiO_2-[bip]-NH_2^+ HSO_4^-.

modes of the Ti–O–Ti band appeared at 650 cm^{-1}.[42] In the case of TiO_2-[bip]-NH, the peak at 2930 cm^{-1} is attributed to the C–H stretching vibrations and the peak at 1121 cm^{-1} is assigned to the C–C–C bending vibrations. Furthermore, in this spectrum the peak at 1037 cm^{-1} can be assigned to the stretching modes of the Si–O band.[43]

In the FTIR spectrum of TiO_2-[bip]-NH_2^+ HSO_4^- the stretching modes of the S=O band of HSO_4^- appeared at 1219 cm^{-1}.[44]

X-ray diffraction (XRD) analysis was performed in order to determine the structure and phase of TiO_2 and TiO_2-[bip]-NH_2^+ HSO_4^- (Fig. 2). In the XRD pattern of TiO_2, five peaks appeared at around 2θ = 25.08, 37.51, 47.96, 54.11 and 62.30 that corresponded to the (101), (004), (200), (105) and (211) facets in the anatase crystal.[45] The XRD pattern of TiO_2-[bip]-NH_2^+ HSO_4^- shows that the immobilization of an ionic liquid on TiO_2 did not change its phase.

The thermogravimetric analysis (TGA) curves of TiO_2 and TiO_2-[bip]-NH_2^+ HSO_4^- are shown in Fig. 3. The TGA curve of TiO_2 shows a slight weight loss (2%) which indicates the high thermal stability of this reagent. The TGA curve of the catalyst displays a completely different curve from TiO_2, which is the result of the modification of its surface during the applied procedure. In this curve the lost weight below 240 °C is related

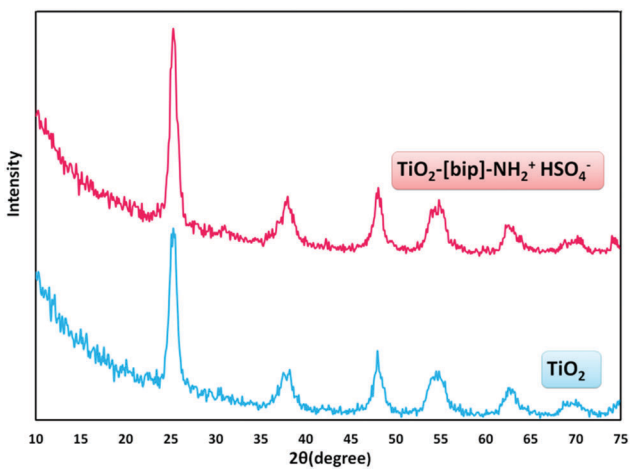

Fig. 2 XRD patterns of TiO_2 and TiO_2-[bip]-NH_2^+ HSO_4^-.

to the removal of the adsorbed water and destruction of the –OH groups. Two weight losses observed at about 240 and 390 °C can be correlated with the decomposition of organic moieties.

The surface morphology and particle size of the TiO_2 and TiO_2-[bip]-NH_2^+ HSO_4^- samples were observed using field

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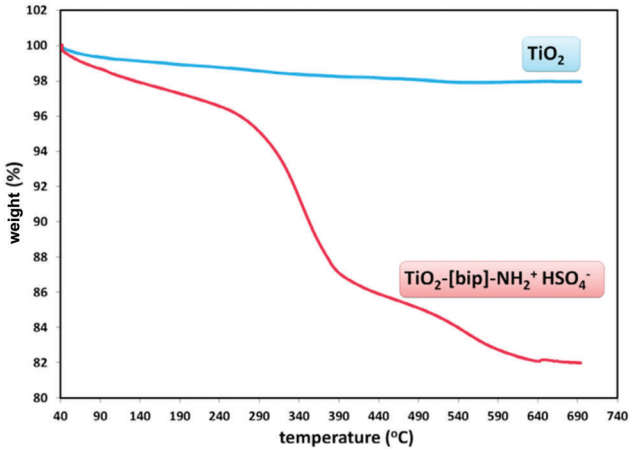

Fig. 3 TGA curves of TiO_2 and TiO_2-[bip]-NH_2^+ HSO_4^-.

emission scanning electron microscopy (FESEM) (Fig. 4). The FESEM images show that the TiO_2 particles are spherical. In the catalyst, the particles are aggregated and their sizes are increased. This is because the presence of ionic groups can cause ion–ion attraction and/or hydrogen bonding between the prepared particles.

Catalytic activity

After careful identification of the prepared reagent and on the basis of its determined formula, it is suggested that this reagent may be able to promote reactions that need an acidic catalyst to speed them up.

At first and in order to confirm this suggestion, the synthesis of *N*,*N*′-diarylformamidines was studied. In this regard, the condensation of aniline with triethyl orthoformate to its corresponding formamidine was chosen as a model reaction and the effect of the amount of catalyst, the amount of orthoformate and the temperature was examined.

After careful studies as tabulated in Table 1, the optimal reaction conditions were obtained as: 2 mmol aniline, 1.5 mmol triethyl orthoformate and 10 mg of TiO_2-[bip]-NH_2^+ HSO_4^- at 60 °C (Table 1, entry 4) (Scheme 2).

After the optimization of the reaction conditions and in order to reveal the generality of this method, we explored the protocol with a variety of simple readily available amines under

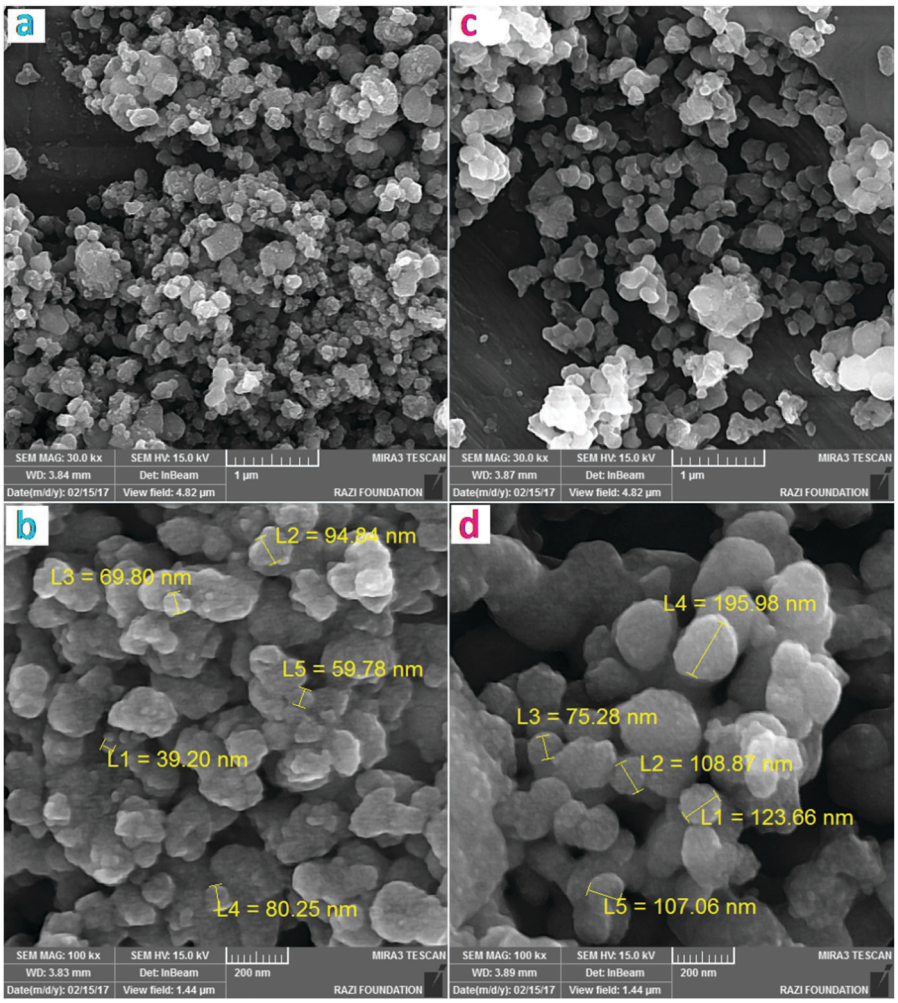

Fig. 4 FESEM images of TiO_2 (a and b) and TiO_2-[bip]-NH_2^+ HSO_4^- (c and d).

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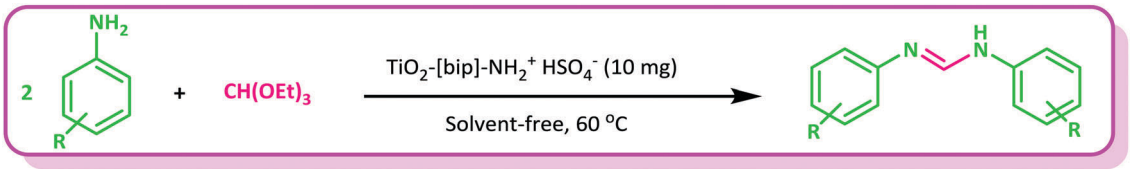
Table 1 Optimization of the reaction conditions catalyzed by TiO_2-[bip]-NH_2^+ HSO_4^-

Entry	Catalyst (mg)	Triethyl orthoformate (mmol)	Temperature (°C)	Time (min)	Conversion (%)
1	40	1.5	60	4	100
2	30	1.5	60	4.5	100
3	20	1.5	60	5	100
4	10	1.5	60	5	100
5	5	1.5	60	8	100
6	10	1.5	40	10	100
7	10	1.5	30	15	100
8	20	1.5	40	7	100
9	20	1.5	30	10	100
10	10	2	60	6	100
11	10	1	60	9	100



Scheme 2 Synthesis of *N,N′*-diarylformamidine derivatives catalyzed by TiO_2-[bip]-NH_2^+ HSO_4^-.

Table 2 Synthesis of various *N,N′*-diphenylformamidines catalyzed by TiO_2-[bip]-NH_2^+ HSO_4^{-a}

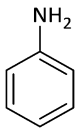
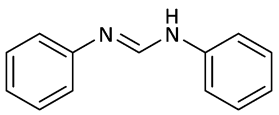
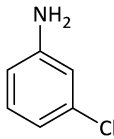
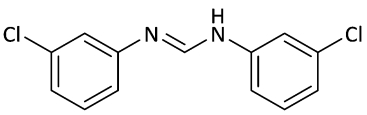
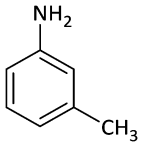
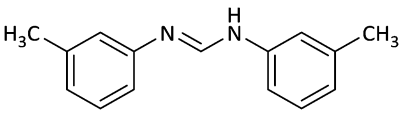
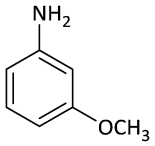
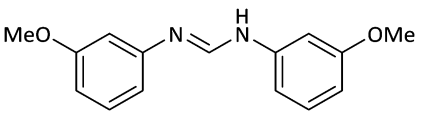
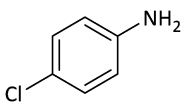
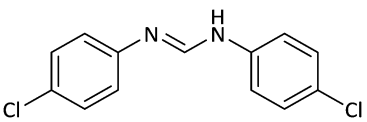
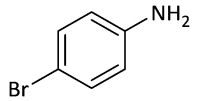
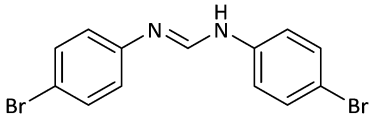
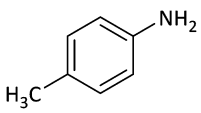
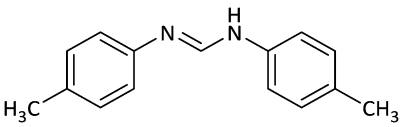
Entry	Amine	Product	Time (min)	Yield[b] (%)	Melting point (°C) Found	Melting point (°C) Reported
1			5	93	134–136	137–139[46]
2			4	93	112–114	114–116[49]
3			4	92	124–126	126–128[50]
4			4	91	98–100	108–110[49]
5			3	92	177–179	182–183.5[49]
6			5	93	183–185	186–187[50]
7			5	91	135–137	141–143[46]

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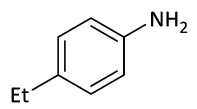
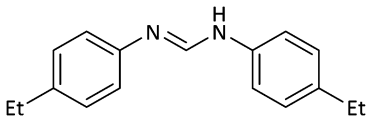
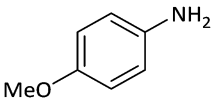
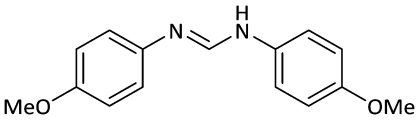
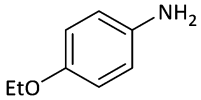
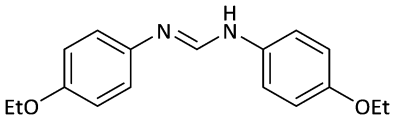
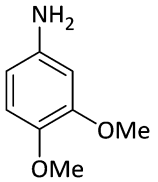
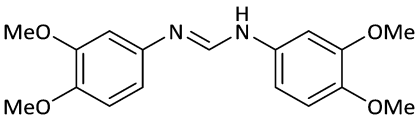
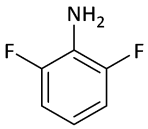
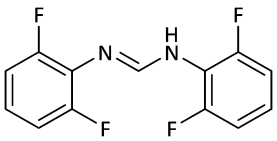
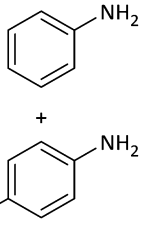
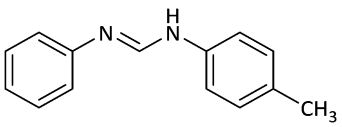
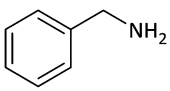
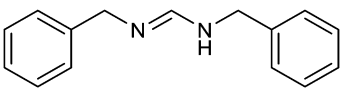
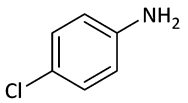
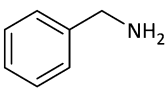
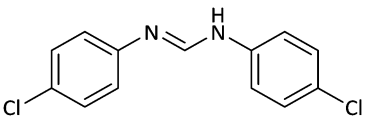
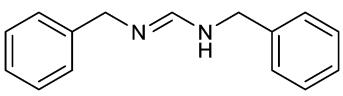
Table 2 (*continued*)

Entry	Amine	Product	Time (min)	Yield[b] (%)	Melting point (°C) Found	Reported
8			5	90	116–118	118–119[49]
9			15	89	110–112	113–115[49]
10			15	83	109–110	113–115[49]
11			20	93	195–197	—
12			30	88	133–135	—
13			40	Mixture of products	—	—
14			1 h	0	—	—
15	 + 	 	3	100 0	— —	— —

[a] Reaction conditions: aromatic amine (2 mmol), triethyl orthoformate (1.5 mmol), and TiO_2-[bip]-NH_2^+ HSO_4^- (10 mg) under solvent-free conditions at 60 °C. [b] Isolated yields.

the selected conditions, and the results are collected in Table 2. As can be seen, aromatic amines having various substituents at different positions of the benzene ring were efficiently converted to their corresponding *N*,*N*′-diarylformamidine derivatives in very short reaction times in high-to-excellent yields (Table 2, entries 1–12). Under the optimal reaction conditions the synthesis of the unsymmetrical diarylformamidines or aliphatic formamidines was unsuccessful (Table 2, entries 13–14). So this method is not useful for the preparation of these types of compounds. In this regard, the selectivity of this method was checked by the competitive reaction of 4-chloro aniline and benzylamine under the selected conditions. The obtained result confirms that 4-chloro aniline was selectively converted to the corresponding product (Table 2, entry 15).

A comparison of the obtained result from the reaction of aniline with orthoformate in the presence of TiO_2-[bip]-NH_2^+ HSO_4^- with some of those reported in the literature (Table 3) shows that the present method is superior in terms of efficiency,

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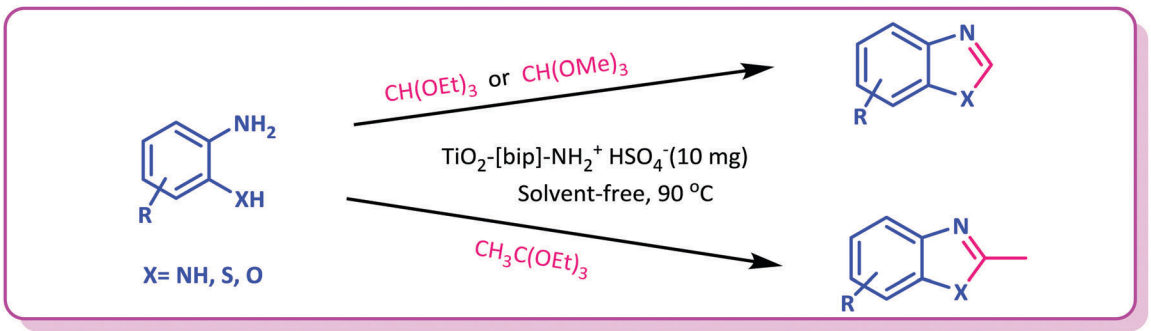
Table 3 Comparison of the obtained results from the reaction of aniline and orthoformate catalyzed by TiO_2-[bip]-NH_2^+ HSO_4^- with some of the best results reported in the references

Entry	Catalyst [ref.]	Reaction conditions	Time (min)	Yield (%)
1	Acetic acid[7]	Solvent-free/140–160 °C	3–4 h	50–80
2	SO_4^{2-}/ZrO_2 (13 mg)[47]	Solvent-free/40 °C	12 h	97
3	HFIP (1 mL)[46]	HFIP/r.t.	3 h	95
4	γ-Fe_2O_3@SiO_2–HBF_4 (2.5 mol%)[48]	Solvent-free/r.t.	4 h	95
5	Nano TiO_2 (10 mg) [this work]	Solvent-free/60 °C	2 h	90
6	TiO_2-[bip]-NH (10 mg) [this work]	Solvent-free/60 °C	2 h	92
7	TiO_2-[bip]-NH_2^+ HSO_4^- (10 mg) [this work]	Solvent-free/60 °C	5 min	93



Scheme 3 Synthesis of benzoxazole, benzothiazole and benzimidazole derivatives catalyzed by TiO_2-[bip]-NH_2^+ HSO_4^-.

Table 4 Synthesis of benzimidazole, benzoxazole, and benzothiazole derivatives catalyzed by TiO_2-[bip]-NH_2^+ HSO_4^- as the catalyst[a]

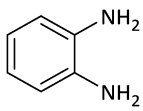
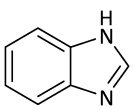
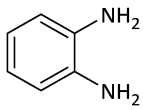
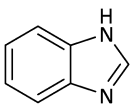
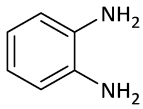
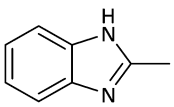
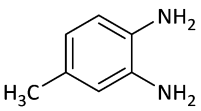
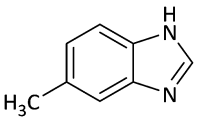
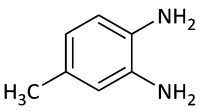
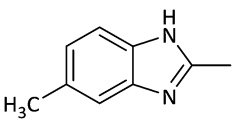
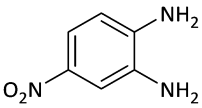
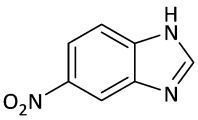
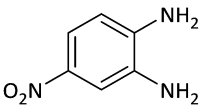
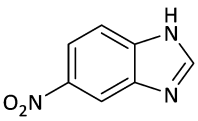
Entry	Amine	Orthoester	Product	Time (min)	Yield[b] (%)	Melting point (°C) Found	Melting point (°C) Reported
1		$CH(OEt)_3$		4	94	168–170	170–171[46]
2		$CH(OMe)_3$		5	92	168–170	170–171[46]
3		$CH_3CH(OEt)_3$		7	90	168–170	172–174[51]
4		$CH(OEt)_3$		10	95	109–111	112–114[51]
5		$CH_3CH(OEt)_3$		15	89	194–196	198–200[51]
6		$CH(OEt)_3$		20	93	203–205	201–202[52]
7		$CH(OMe)_3$		30	90	203–205	201–202[52]

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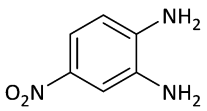
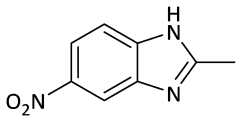
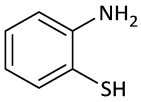
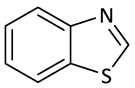
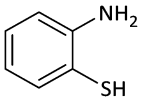
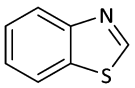
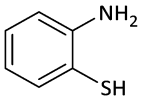
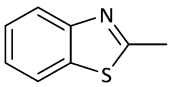
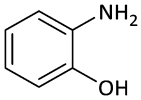
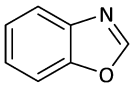
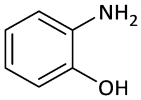
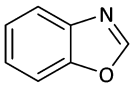
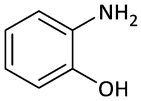
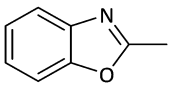
Table 4 (*continued*)

Entry	Amine	Orthoester	Product	Time (min)	Yield[b] (%)	Melting point (°C) Found	Reported
8		$CH_3CH(OEt)_3$		35	89	220–222	227–228[52]
9		$CH(OEt)_3$		2	95	Oil	Oil[53]
10		$CH(OMe)_3$		2	92	Oil	Oil[53]
11		$CH_3CH(OEt)_3$		2	93	Oil	Oil[53]
12		$CH(OEt)_3$		5	92	Oil	Oil [53]
13		$CH(OMe)_3$		7	91	Oil	Oil[53]
14		$CH_3CH(OEt)_3$		2	91	Oil	Oil[53]

[a] Reaction conditions: substrate (1 mmol), triethyl orthoformate (1.5 mmol), and TiO_2-[bip]-NH_2^+ HSO_4^- (10 mg) under solvent-free conditions at 90 °C. [b] Isolated yields.

Table 5 Comparison of the obtained results from the reaction of 1,2-phenylenediamine and orthoformate catalyzed by TiO_2-[bip]-NH_2^+ HSO_4^- with some of the best reported results in the literature

Entry	Catalyst [Ref.]	Reaction conditions	Time (min)	Yield (%)
1	KSF (1 g)[27]	Toluene/reflux	12 h	79
2	Sulfamic acid (5 mol%)[29]	CH_3OH/r.t.	1 h	98
3	$ZrCl_4$ (10 mol%)[30]	CH_3OH/r.t.	2 h	93
4	Hexafluoroisopropanol (HFIP) (1 ml)[31]	HFIP	2 h	92
5	$[EtNH_3][NO_3]$[32]	U.S./45 °C	20	86
6	HBF_4–SiO_2 (40 mg)[33]	Solvent free/80 °C	50	94
7	Silica tungstic acid (50 mg)[34]	Solvent free/80 °C	8	90
8	Nano TiO_2 (10 mg) [this work]	Solvent-free/90 °C	1 h	90
9	TiO_2-[bip]-NH (10 mg) [this work]	Solvent-free/90 °C	30	93
10	TiO_2-[bip]-NH_2^+ HSO_4^- (10 mg) [this work]	Solvent free/90 °C	4	94

reaction time and catalyst amount. As it can be seen, TiO_2 and TiO_2-[bip]-NH are also able to catalyze these types of reactions, but in longer reaction times than TiO_2-[bip]-NH_2^+ HSO_4^- (Table 3, entries 5 and 6). These results are clear evidence to confirm the important role of the preformed modification in the catalyst to obtain the best performance.

After the successful application of TiO_2-[bip]-NH_2^+ HSO_4^- as the catalyst in the synthesis of *N*,*N*′-diarylformamidines, we decided to use this reagent for the promotion of the synthesis of benzoxazoles, benzothiazoles, and benzimidazoles. The obtained results showed that the synthesis of benzimidazole using the previous reaction conditions can be performed in long reaction times, so we increased the amount of catalyst and the temperature. Although by increasing the temperature, the reaction time is reduced, increasing the amount of catalyst did not have a considerable effect on the reaction time. The best result was obtained using 10 mg of TiO_2-[bip]-NH_2^+ HSO_4^- at 90 °C (Scheme 3).

Under these optimal reaction conditions, different orthoesters (including trimethyl orthoformate, triethyl orthoformate, and triethyl orthoacetate) were used and a variety of benzimidazole, benzoxazole and benzothiazole derivatives were obtained in good to excellent yields (Table 4). It is apparent that 1,2-phenylene diamines containing electron-donating groups gave

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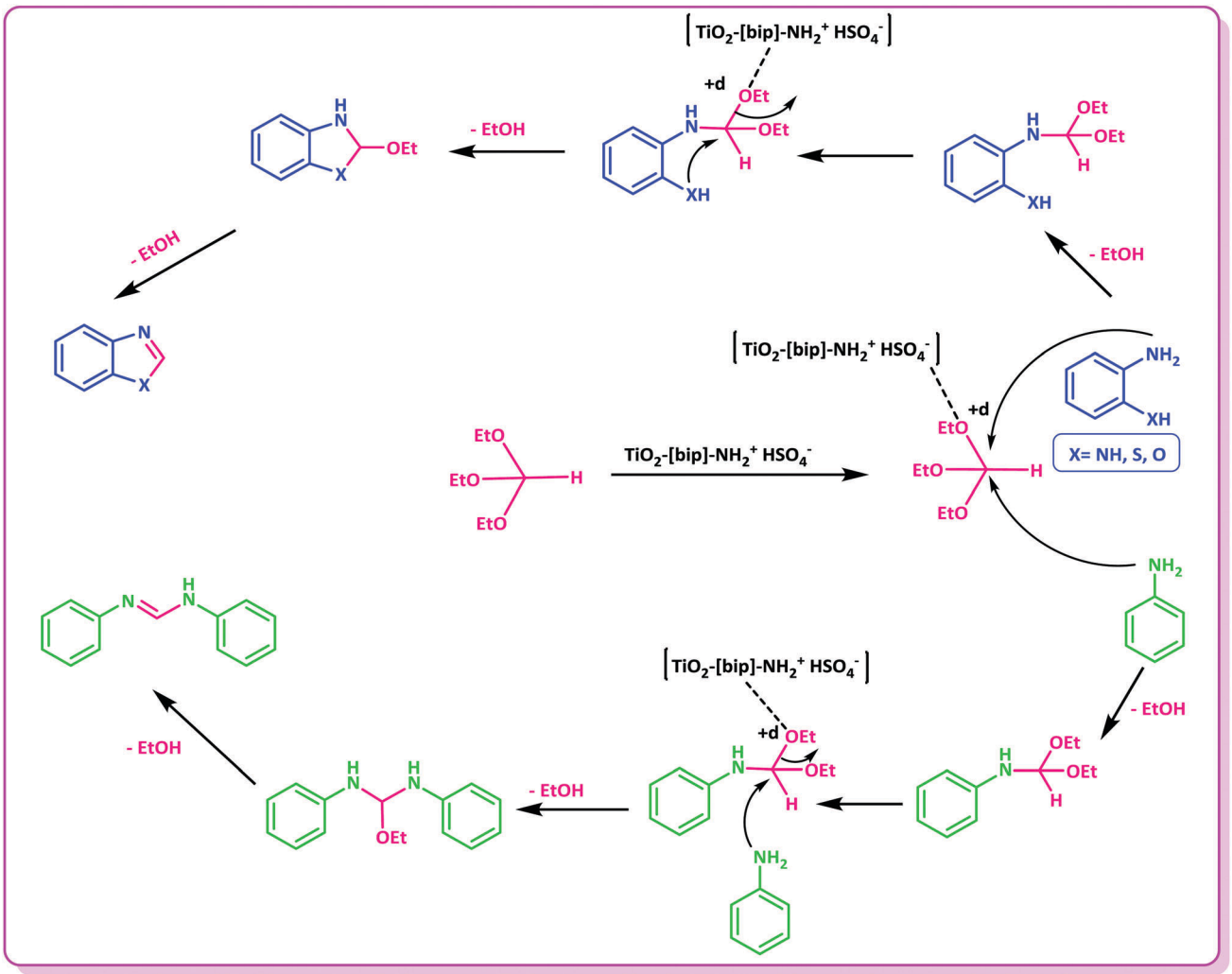

Scheme 4 The proposed mechanism of the studied reactions.

the desired products in excellent yields (Table 4, entries 4 and 5), whereas 1,2-phenylene diamines with electron-withdrawing groups reacted at longer reaction times (Table 4, entries 6–8). The method was also found to be useful for the synthesis of benzothiazoles and benzoxazoles derivatives, in very short reaction times (Table 4, entries 9–14).

In order to show the efficiency of the present method, we have compared our obtained results from the reaction of 1,2-phenylenediamine and orthoformate in the presence of TiO_2-[bip]-NH_2^+ HSO_4^- with some of the reported results in the literature and also with the obtained results using nano TiO_2 and TiO_2-[bip]-NH (Table 5). It is definite that the present method is superior in terms of the reaction times, efficiency and catalyst amount.

The proposed mechanism of the studied reactions in the presence of TiO_2-[bip]-NH_2^+ HSO_4^- as the catalyst is shown in Scheme 4. On the basis of this mechanism, TiO_2-[bip]-NH_2^+ HSO_4^- acts as a Brönsted acidic catalyst to activate the *ortho* ester against nucleophilic attack.

We also examined the possibility of using the present method for a large-scale reaction *via* the reaction of 4-chlorobeaniline (20 mmol) and triethyl orthoformate (15 mmol) using 0.1 g of TiO_2-[bip]-NH_2^+ HSO_4^- at 60 °C. The reaction was completed within 3 min, and the desired product was obtained in 90% yield, almost similarly in all respects with the 1 mmol scale entry (Table 2, entry 5). The above result indicated that a large-scale reaction is achievable using TiO_2-[bip]-NH_2^+ HSO_4^- as the catalyst.

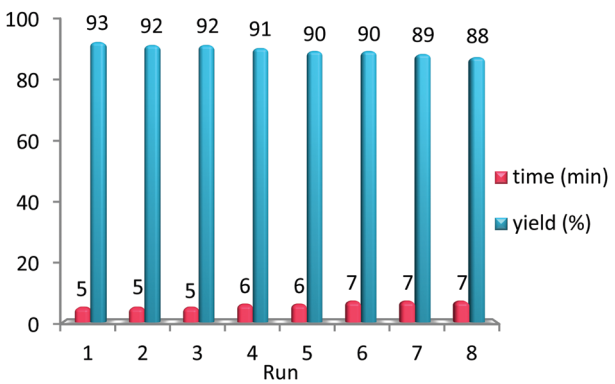

Fig. 5 Reusability of the catalyst.

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To check the recovery capability of the catalyst, the reaction of aniline with triethyl orthoformate under the optimized reaction conditions was studied again. After completion of the reaction, ethyl acetate was added and the catalyst was separated by filtration. This process was repeated more than eight times and all the reactions were well done without significant changes in the reaction time and yield, which clearly shows the practical recyclability of this catalyst (Fig. 5).

Conclusions

In conclusion, in this study TiO_2-[bip]-NH_2^+ HSO_4^- is prepared, identified and used as a highly powerful catalyst for the simple and efficient synthesis of *N*,*N*′-diarylformamidines, benzoxazoles, benzothiazoles, and benzimidazoles. The procedure has several advantages such as high reaction rates, ease of preparation and handling of the catalyst, a simple and green experimental procedure and the use of an inexpensive and reusable catalyst. We believe that this process can be a useful and attractive strategy in view of its economic and environmental advantages.

Conflicts of interest

There are no conflicts to declare.

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