

Polyaniline, Polyaniline/SiO₂ and Poly(4-vinylpyridine): as Highly Efficient and Recyclable Green Heterogeneous Basic Catalysts for the Three-Component Synthesis of Tetrahydrobenzopyran and 3,4-Dihydropyrano[*c*]Chromene Derivatives

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ABSTRACT: Polyaniline, polyaniline/SiO₂, and poly(4-vinylpyridine) are highly effective base catalysts for the synthesis of tetrahydrobenzo[*b*]pyran and 3,4-dihydropyrano[*c*]chromene derivatives by the one-pot three-component condensation reaction of aryl aldehydes, malononitrile and α -hydroxy or α -amino activated C–H acids such as 1,3-cyclohexanedione, dimedone, 4-hydroxy-6-methylpyrone, 4-hydroxycoumarin, 1,3-dimethylbarbituric acid, and 1,3-dimethyl-6-amino uracil. The remarkable advantages of this new procedure are high yields, short experimental time, mild reaction condition, low cost and easy preparation of the catalysts, and no need for any workup and purification after completion of the reaction. In addition, these catalysts exhibited excellent recoverability without a negligible decrease of their activities after at least six cycles of reaction.

KEYWORDS: Multi-component reaction, Tetrahydrobenzopyrans; 3,4-Dihydropyrano[*c*]Chromenes; Green solvent; Heterogeneous catalyst, Ionic liquid.

INTRODUCTION

Recently, the design and use of environmentally benign solid acid/base heterogeneous catalysts to decrease the amount of toxic waste and byproducts from chemical processes have been highlighted. The main advantages

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of heterogeneous catalysts are easy separation from the reaction mixture after the reaction completion and existence of many active sites on their surface [1-3]. In contrast to the widespread studies on the acid heterogeneous catalysts, few numbers of studies have been conducted on the base heterogeneous catalysts [4].

Heterogeneous base catalyst can act efficiently in organic transformations with low cost and minimal environmental impact because of the possibility of simplifying the production and purification processes under mild conditions. Heteroatoms existing on the surface of basic heterogeneous catalysts would be able to interact attractively with proton which is important in many organic reactions [4].

Several bases heterogeneous materials including zeolites [5], alkali metals supported on alumina (Na/NaOH/c-Al₂O₃) [6], clay minerals [7], hydrotal-cites (HDT) [8], metal oxides and mixed metal oxides such as magnesium oxide (MgO) and magnesium-lanthanum mixed oxides [9] have been reported as the efficient catalysts. The replacement of these inorganic solids by polymeric base catalysts leads to decrease corrosion and environmental problems, accompanied by easier separation and recovery of the catalysts.

Polyaniline, polyaniline/SiO₂ and poly(4-vinylpyridine) have known as highly efficient base heterogeneous catalysts, which have received intensive interest due to their superficial synthesis, good environmental stability, ease of conductivity control by changing the oxidation and protonation states and inexpensive monomers [10,11]. Polyaniline and polyaniline-supported metal oxides are commonly synthesized by oxidizing aniline monomers using electrochemical or chemical methods [12-14]. In addition, they have been extensively used as solid or redox catalysts for various organic transformations such as oxidation reactions, dehydrogenation reactions, Michael addition, Suzuki-Miyaura cross-coupling, esterification and condensation reactions [15-18]. Recently, poly(4-vinylpyridine) has been used as a base catalyst in some organic reactions such as esterification of carboxylic acids with alcohols, conversion of iminodithiazoles to aryl isothiocyanates and synthesis of quinazoline and chromene derivatives [19,20].

Tetrahydrobenzo[*b*]pyran and pyrano[*c*]chromene derivatives have been concerned increasing interest due to their wide range of biological properties and many methods have been reported for the synthesis of these compounds [21,22]. The conventional procedure for

the synthesis of chromenes is condensation of 1,3-dicarbonyl compounds with aromatic aldehyde and malononitrile under refluxing in acetic acid [23] or ethanolic piperidine [24]. However, various catalysts have been used for the synthesis of these compounds such as diammonium hydrogen phosphate, (DAHP) [25], hexadecyldimethylbenzyl ammonium bromide [26] or by electrochemical reactions [27] and also using microwave in organic solvents i.e. ethanol, methanol or in water [28], there are major drawbacks for these reports including low yields, using of expensive and commercially unavailable catalyst, long reaction time and high temperature.

As part of our current studies on design and development of new methods for the synthesis of heterocyclic compounds [29-34], we now turn our attention to the reactivity of heterogeneous base catalysts such as polyaniline, polyaniline/SiO₂ or poly(4-vinylpyridine) on the three-component reaction of aryl aldehydes, malononitrile and α -hydroxy or α -amino activated C-H acids such as 1,3-cyclohexanedione, dimedone, 4-hydroxy-6-methylpyrone, 4-hydroxy-coumarin, 1,3-dimethylbarbituric acid and 1,3-dimethyl-6-amino uracil under thermal conditions (Scheme 1).

EXPERIMENTAL SECTION

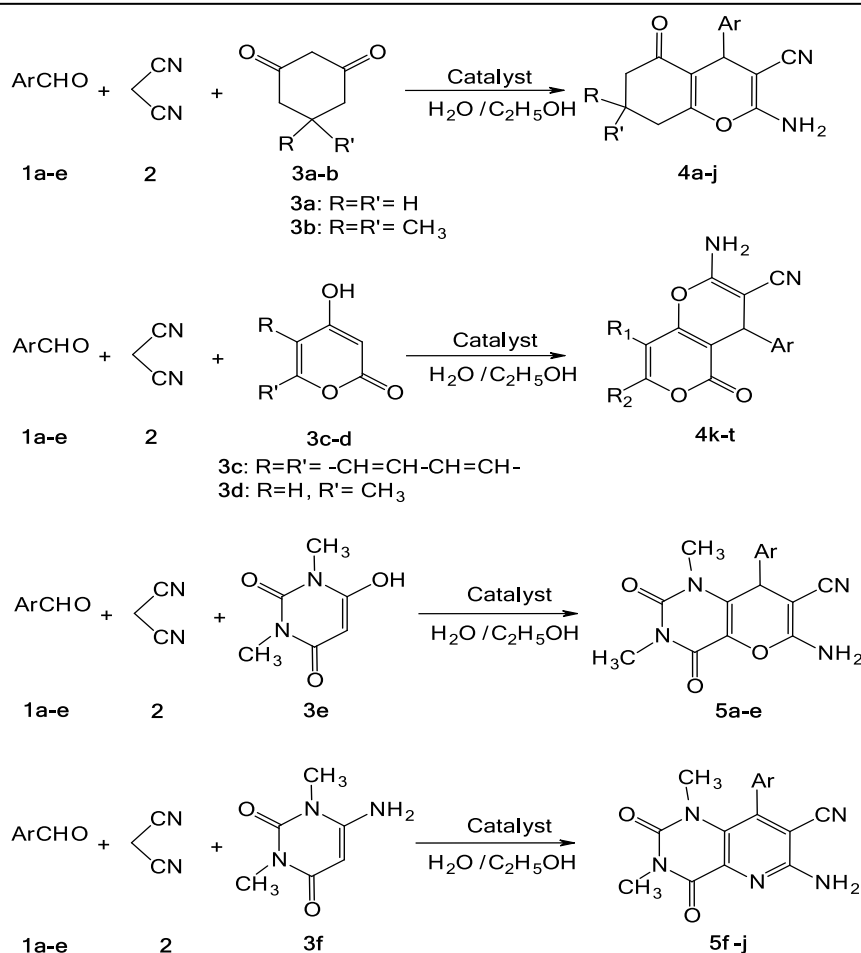
Poly(4-vinylpyridine), aniline (was distilled before use), malononitrile, aldehydes and α -hydroxy or α -amino activated C-H acids were commercially available, obtained from Merck Chemical Company and was used without further purification. Melting points were measured on an Electrothermal-9100 apparatus and are uncorrected. IR spectra were recorded on a Bruker FT-IR Tensor 27 infrared spectrophotometer. The ¹H, ¹³C NMR spectra were recorded with BRUKER DRX-400 (400 and 100 MHz, respectively) spectrometers in DMSO-*d*₆ with TMS as internal standard.

Catalysts preparation

The details for the synthesis of polyaniline and polyaniline/SiO₂ have been reported in the literature [18, 35].

General procedure for the preparation of tetrahydrobenzopyran and 3,4-dihydropyrano [c] chromene derivatives

A mixture of aldehyde **1** (2 mmol), malononitrile **2** (2 mmol), α -hydroxy or α -amino activated C-H acids



Scheme 1: Synthesis of pyran annulated heterocyclic systems **4a–5j** via a three-component reaction in the presence of polyaniline, polyaniline/SiO₂ or poly(4-vinylpyridine) as a highly effective heterogeneous base catalyst.

(2 mmol) and the catalyst (polyaniline: 0.15 g, 10 mol%, poly(4-vinylpyridine): 0.06 g, 10 mol%, polyaniline/SiO₂: 0.18g, 10 mol%) in H₂O (10 mL) in ethanol (20 mL) was refluxed under stirring for the time reported in Table 2 (the progress of the reaction being monitored by TLC and hexane/ethyl acetate used as an eluent). After the reaction completion, the catalyst was separated by filtration from the reaction mixture. Then the product was precipitated from the reaction mixture by cooling. Further purification was done by recrystallizing from ethanol to get pure product.

RESULTS AND DISCUSSION

In order to optimize the reaction conditions, reaction of benzaldehyde **1a** with dimedone **3b**, malonitrile **2**, and polyaniline catalyst as a simple model substrate

was investigated in various conditions. Initially, the effect of protic and aprotic solvents was investigated. Notably, the model reaction was carried out efficiently in protic solvents such as H₂O and ethanol with high yields under reflux condition (Table 1, entries 3, 4). By using aprotic polar solvent such as CH₃CN, the reaction afforded the corresponding 4*H*-benzopyran **4f** with a moderate yield after 50 min in reflux (Table 1, entry 7).

In the absence of any catalyst, no valuable results were obtained (Table 1, entry 1). In the presence of bases such as Et₃N and DABCO, the model reaction proceeded slowly with low yield of the desired product (Table 1, entry 2,3). Surprisingly, using polyaniline catalyst in the reaction model led to high yield of **4f** product with short experimental time in EtOH/ H₂O and reflux condition (Table 1, entry 10).

Table 1: Solvent effect on the three-component reaction for the synthesis of 4f in the presence of polyaniline.

Entry	Catalyst (mol%)	β -diketone	Solvent	Temperature (°C)	Time (min)	Yield (%)
1	-	3b	EtOH	Reflux	240	10
2	Et ₃ N (1eq)	3b	EtOH	Reflux	120	20
3	DABCO(10)	3b	EtOH	Reflux	120	25
4	Polyaniline (10)	3b	Toluene	Reflux	200	69
5	Polyaniline (10)	3b	Acetonitrile	Reflux	50	78
6	Polyaniline (10)	3b	H ₂ O	r. t	50	25
7	Polyaniline (10)	3b	H ₂ O	Reflux	45	85
8	Polyaniline (5)	3b	EtOH/H ₂ O	Reflux	25	65
9	Polyaniline (7)	3b	EtOH/H ₂ O	Reflux	30	72
10	Polyaniline (10)	3b	EtOH/H ₂ O	Reflux	20	93
11	Polyaniline (15)	3b	EtOH/H ₂ O	Reflux	20	93

Additionally, different amounts of polyaniline catalyst have been checked in the model reaction and 10 mol% of the catalyst showed the best result (Table 1, entry 10).

With the obtained optimal conditions, synthesis a wide library of tetrahydrobenzo[b]pyran and 3,4-dihydropyrano[c]chromene derivatives was then carried out by one-pot three-component condensation reaction of aryl aldehydes, malononitrile and α -hydroxy or α -amino activated C–H acids such as 1,3-cyclohexanedione, dimedone, 4-hydroxy-6-methylpyrone, 4-hydroxycoumarin, 1,3-dimethylbarbituric acid and 1,3-dimethyl-6-amino uracil (Table 2). All reactions produced good to excellent yields and a wide range of both aromatic aldehydes containing electron-donating and electron-withdrawing groups without any significant substituent effect were synthesized.

A plausible mechanism for the synthesis of product **4** in the presence of polyaniline catalyst is outlined in Scheme 2. a) The Knoevenagel reaction occurs via an initial formation of α -cyanocinnamionitrile derivatives **I**, from the condensation of aromatic aldehydes **1** and malononitrile **2**. b) The methylene of **3** is activated by NH of polyaniline and reacts with the electrophilic C=C double bond of **I**, giving intermediate **II**. c) Intermediate **II** is then cyclized by nucleophilic attack of the OH group to the cyano (CN) moiety to produce the final product.

Recycling of catalyst

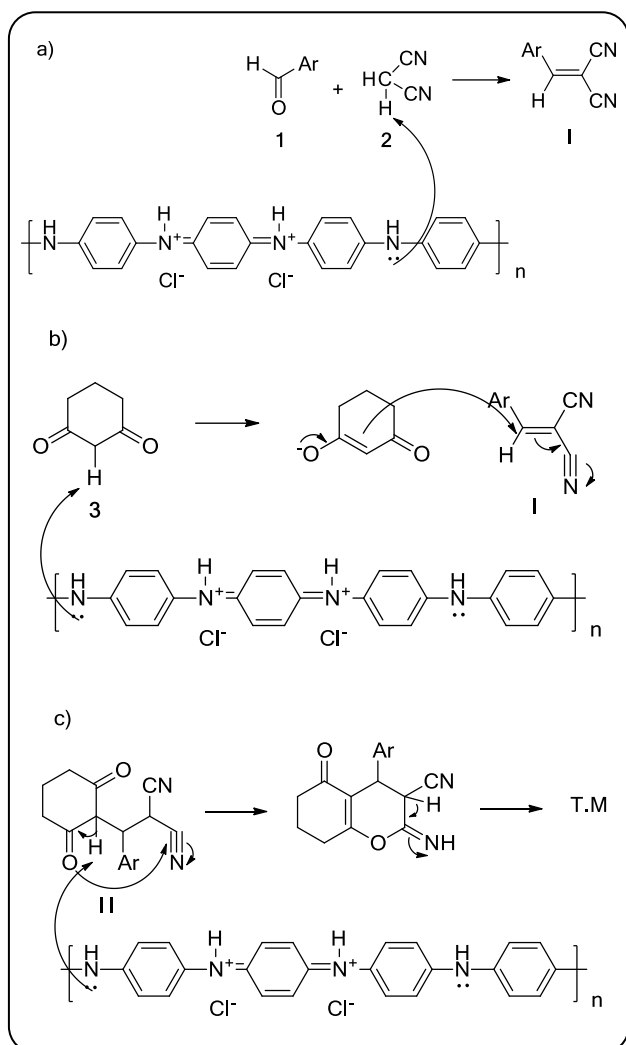
Due to the additional advantage of solid catalysts, the recovering of the used catalysts (polyaniline, polyaniline/SiO₂ and poly(4-vinylpyridine)) were explored. Therefore, the catalyst could be recovered by filtering after completion the reaction and washed with water, dried under vacuum and reused in a subsequent reaction. The reaction scale was amplified 6 cycles to ensure that good quality of catalyst was available for us to perform several recycling reactions. The recycling results of polyaniline, polyaniline/SiO₂ and poly(4-vinylpyridine) are reflected in Fig. 1.

CONCLUSIONS

In summary, we have shown that polyaniline, polyaniline/SiO₂ and poly(4-vinylpyridine) are highly effective catalysts and provide a new and useful method for the synthesis of pyran annulated heterocyclic systems via multi-component reaction of aldehydes, α -hydroxy or α -amino activated C–H acid compounds and malononitrile. This procedure offers several advantages including high yields, operational simplicity, clean reaction conditions and environmentally friendly catalyst, which makes it a useful and attractive method for the synthesis of these compounds.

Table 2: Three-component process for the synthesis of 4a-5j in the presence of high surface area catalyst, poly(4-vinylpyridine), polyaniline and polyaniline/SiO₂.

Comp No.	Ar	β-Diketone	poly(4-vinylpyridine)		polyaniline		polyaniline/SiO ₂		M.P. (°C)
			Time (min.)	Yield (%)	Time (min.)	Yield (%)	Time (min.)	Yield (%)	
4a	C ₆ H ₅	3a	25	86	11	87	15	85	229-231
4b	4-MeOC ₆ H ₄	3a	30	81	14	85	16	83	188-190
4c	3-NO ₂ C ₆ H ₄	3a	22	88	5	90	10	90	208-210
4d	2,4-ClC ₆ H ₃	3a	22	87	4	94	8	92	221-223
4e	4-ClC ₆ H ₄	3a	25	84	8	92	12	89	224-225
4f	C ₆ H ₅	3b	24	95	10	93	14	89	226-228
4g	4-MeOC ₆ H ₄	3b	26	85	12	90	15	89	195-197
4h	3-NO ₂ C ₆ H ₄	3b	14	98	4	97	8	95	213-215
4i	2,4-ClC ₆ H ₃	3b	16	94	3	97	9	92	113-115
4j	4-ClC ₆ H ₄	3b	20	93	8	95	12	92	238-240
4k	C ₆ H ₅	3c	28	84	13	89	15	87	255-257
4l	4-MeOC ₆ H ₄	3c	35	78	13	84	17	84	242-244
4m	3-NO ₂ C ₆ H ₄	3c	25	85	7	93	11	90	262-264
4n	2,4-ClC ₆ H ₃	3c	22	88	6	95	13	94	255-257
4o	4-ClC ₆ H ₄	3c	25	83	10	90	15	90	262-264
4p	C ₆ H ₅	3d	30	80	15	87	18	86	220-222
4q	4-MeOC ₆ H ₄	3d	35	78	17	86	20	85	199-201
4r	3-NO ₂ C ₆ H ₄	3d	25	88	10	93	12	93	231-233
4s	2,4-ClC ₆ H ₃	3d	25	90	8	95	10	90	224-226
4t	4-ClC ₆ H ₄	3d	27	87	10	92	12	91	220-222
5a	C ₆ H ₅	3e	35	78	12	90	14	91	288-290
5b	4-MeOC ₆ H ₄	3e	42	74	15	93	18	90	130 dec
5c	3-NO ₂ C ₆ H ₄	3e	30	84	10	96	12	94	151-153
5d	2,4-ClC ₆ H ₃	3e	30	80	8	97	12	95	168-170
5e	4-ClC ₆ H ₄	3e	35	79	10	92	14	90	252-254
5f	C ₆ H ₅	3f	30	80	12	90	14	91	210-212
5g	4-MeOC ₆ H ₄	3f	40	72	15	93	18	90	114-116
5h	3-NO ₂ C ₆ H ₄	3f	25	84	10	96	12	94	150 dec
5i	2,4-ClC ₆ H ₃	3f	25	83	8	97	12	95	252-254
5j	4-ClC ₆ H ₄	3f	30	80	10	92	14	90	161-163



Scheme 2: A plausible mechanism for the formation of the product 4.

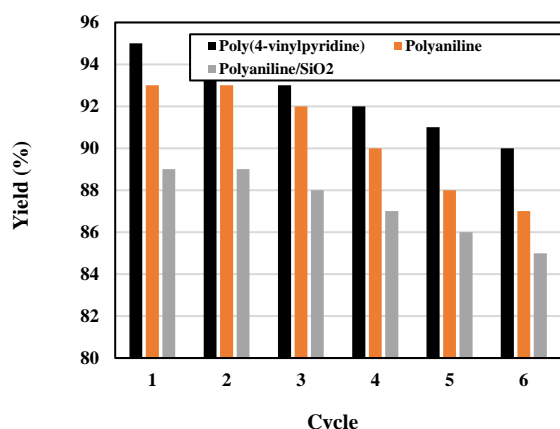


Fig. 1: The reusability of catalysts for the synthesis of compound 4f

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