

Polyaniline/SiO₂ Catalyzed One-pot Synthesis of Tetrahydrobenzo[*b*]pyran Derivatives

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ABSTRACT

Polyaniline/SiO₂ is an efficient catalyst for the synthesis of tetrahydrobenzo[*b*]pyran derivatives from a one-pot, three component, condensation of aldehydes, malononitrile and dimedone at room temperature. This protocol has several advantages such as high yield, a simple work up procedure, low toxicity and easy recovery and reusability of the catalytic material. The catalyst has been readily prepared and characterized by means of thermal analysis (TG-DTA), X-ray diffraction (XRD), scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FT-IR).

KEYWORDS

Chemical oxidative method, Polyaniline/SiO₂, tetrahydrobenzo[*b*]pyran.

1. Introduction

In recent years there have been extensive studies in the use of conducting polyanilines because of their wide range of electrical, electrochemical and optical properties, as well as their good stability.^{1–4} Polyaniline is commonly synthesized by oxidizing aniline monomers using electrochemical or chemical methods.^{5–7} Polyaniline-supported catalysts often display good environmental, thermal and chemical stability as well as interesting electrical and optical properties, facile redox and pH-switching behavior.⁸ Polyaniline and polyaniline-supported metal oxides have been extensively used as solid acid or redox catalysts for various organic transformations such as oxidation, dehydrogenation, condensation, Michael, Suzuki–Miyaura cross-coupling and esterification reactions.^{9–16}

The 4*H*-pyran group is a constituent of a series of natural products and its derivatives represent a major class of heterocycles.^{17,18} These compounds continue to attract attention in chemistry due to their useful biological and pharmacological properties such as anticoagulant, spasmolytic, diuretic and anticancer properties.¹⁹ It has also been reported that some benzopyran derivatives possess photochemical activities.²⁰ Realizing the importance of these compounds, various methods for the synthesis of tetrahydro-4*H*-benzopyran derivatives have been developed. The conventional synthesis of tetrahydrobenzo[*b*]pyrans involves the condensation of aldehydes with malononitrile and dimedone under reflux in acetic acid.²¹ Recently, several alternative methods towards tetrahydrobenzo[*b*]pyrans have been reported, including the use of 1,1,3,3-*N,N,N,N*-tetramethylguanidinium trifluoroacetate (TMGT) as an ionic liquid,²² diammonium hydrogen phosphate (DAHP),²³ molecular iodine,²⁴ *N*-methylimidazole,²⁵ sodium selenate,²⁶ and hexadecyldimethylbenzyl ammonium bromide (HDMBAB).²⁷ Additionally, electrochemical reactions,²⁸ microwave heating in the solid state²⁹ and cerium (III) chloride have been utilized to synthesize the tetrahydrobenzo[*b*]pyran motif.³⁰ However, several of these methods are plagued by one or more drawbacks such as long reaction times, the use of volatile solvents, low yields and harsh reaction conditions employed. It is therefore desirable to develop an improved route for the

synthesis of tetrahydrobenzo[*b*]pyran under mild reaction conditions.

In continuation of our interest towards the development of new heterogeneous catalyst for the synthesis of bioactive heterocycles,^{31–34} herein, we report an efficient protocol for the synthesis of tetrahydrobenzo[*b*]pyran derivatives over polyaniline/SiO₂ by way of a one pot condensation of aldehydes, malononitrile and dimedone.

2. Results and Discussion

The synthesis of tetrahydrobenzo[*b*]pyran derivatives by way of the condensation of aldehydes, malononitrile and dimedone as catalyzed by polyaniline/SiO₂, is shown in (Scheme 1). The polyaniline/SiO₂ catalyst was prepared by using a chemical oxidative method. The details of the synthesis and characterization of this material are described in the experimental section of this paper. Of importance to this paper was the utilization of a model reaction, based on Scheme 1, for the development of a stable catalyst system which would perform the desired reaction under optimized conditions, such as the weight percentage of catalyst on the support and the amount of catalyst and type of solvent utilized.

The stability of the prepared catalyst was tested in different solvents (methanol, acetone, acetonitrile and ethanol) to determine the stability of the material in these solvents. This was done by spectrophotometric analysis in which the extent of degradation of the catalyst was monitored by the change in optical density of the solution (catalysts solutions were monitored after 15 days at room temperature). The results are summarized in Table 1 and shows that the catalyst had the best stability in ethanol with the lowest optical density after the time period measures. Hence, in order to get the optimum reaction condition, the reactions of 4-chlorobenzaldehyde, malononitrile and dimedone using ethanol as a solvent at room temperature was considered as a standard model reaction.

To examine the effect of the catalyst composition on the activity, various amounts of polyaniline supported SiO₂ were used and the results are summarized in Table 2. Pure silica exhibits poor catalytic activity in terms of reaction time and yield of the products. Pure polyaniline however, gave a good yield of

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Table 5 Comparison of 10 wt % polyaniline/SiO₂ with other catalyst for the synthesis of tetrahydrobenzo[*b*]pyran.

Entry ^a	Catalyst	Solvent	Time/h	Yield/% ^b	Ref.
1	Molecular iodine	DMSO	3–4	85–90	24
2	Sodium selenate	EtOH:H ₂ O	2.5–3.5	90–98	26
3	HDHBAB	H ₂ O	6–8	84–95	27
4	10 wt % Polyaniline/SiO ₂	EtOH	1–1.1	91–93	c

^a Reaction conditions: aldehyde (1 mmol), malononitrile (1 mmol), dimedone (1 mmol), catalyst (0.1 g) and ethanol 15 mL.^b Isolated yields.^c This work.

an open capillary and are uncorrected. TG-DTA was performed using PYRIS 1 Thermogravimetric analysis. IR spectra were recorded on JASCO-FT-IR/4100, Japan, in KBr disc. Thin-layer chromatography was performed on Merck pre-coated silica gel 60-F254 plates. ¹H NMR spectra were recorded on an 300 MHz FT-NMR spectrometer in CDCl₃ as a solvent and chemical shifts values are recorded δ (ppm) relative to tetramethylsilane (Me₄Si) as an internal standard. The X-ray diffraction (XRD) patterns were recorded on Bruker 8D advance X-ray diffractometer using monochromator Cu-Kα radiation in which wavelength λ = 1.5405 Å. Conventional scanning electron microscopy (SEM) images were obtained on JEOL; JSM-6330 LA operated at 20.0 kV and 1.0000 nA.

4.1. Preparation of Pure Silica

Silica samples were synthesized by using a sol-gel process requiring the addition of tetraethyl ortho-silicate (TEOS) (16 mL) was in aqueous ammonia (60 mL). The resulting reaction mixture was then stirred continuously for 1 h at r.t. to obtain uniform silica spheres. The resulting silica material was next retrieved by centrifugation, washed with distilled water and dried at 110 °C for overnight. Finally, the resulting material was calcined at 500 °C for 5 h under air atmosphere to produce solid porous silica materials.

4.2. Preparation of Polyaniline/SiO₂ Catalyst

The series of polyaniline/SiO₂ catalytic materials with varying aniline (10, 20, 30 wt %) and SiO₂ were prepared by chemical oxidative method. In a typical procedure, 10 wt % polyaniline/SiO₂ catalyst was synthesized by slowly mixing a solution of aniline (0.3 mL) in distilled water (30.8 mL) with concentrated sulphuric acid (0.61 mL) at 5–10 °C. The resultant mixture was

successively treated with aqueous potassium persulphate (16 mL) (used as an oxidant) and solid porous silica (2.68 g). The mixture was then kept at 5 °C and stirring continued for 5–6 h resulting in a precipitate that was obtained by filtration. This precipitate was next washed with distilled water and acetone. The product, polyaniline/SiO₂ salt, was then dried in an oven at 70 °C for 3 h. Similarly, 20 and 30 wt % polyaniline/SiO₂ catalysts were prepared in the same manner.

4.3. General Procedure for the Synthesis of Tetrahydrobenzo[*b*]pyran 4(a–h)

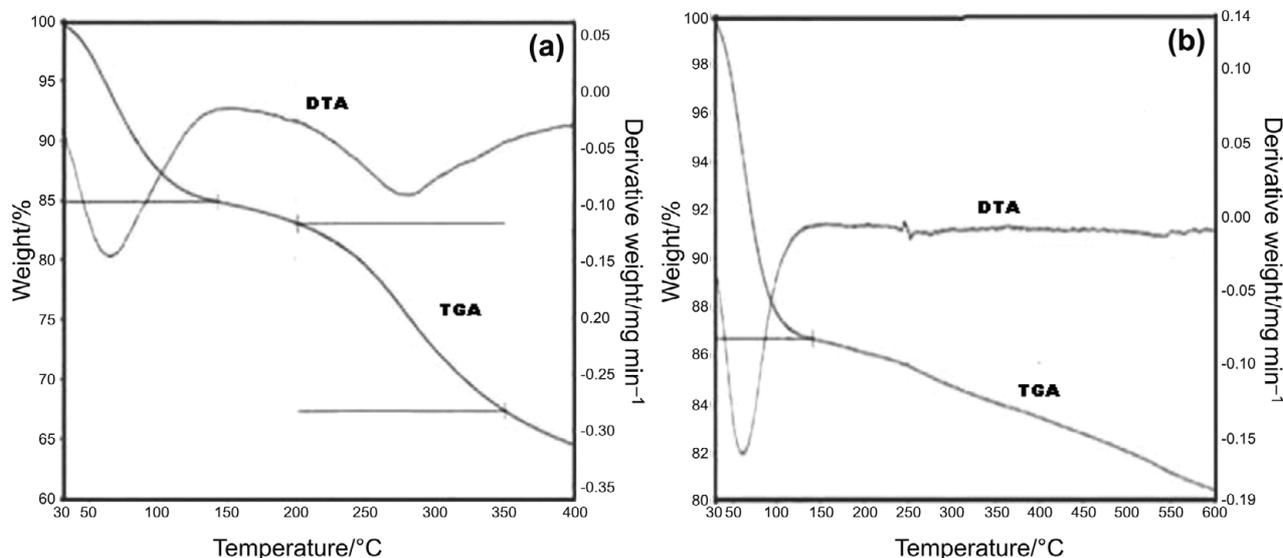
A mixture of aldehydes (1 mmol), malononitrile (1 mmol) and catalytic amount of polyaniline/SiO₂ (0.1 g) in ethanol (15 mL) was stirred for 5–10 min before been treated with dimedone (1 mmol) and stirring continued at 60 °C for 60–70 min. The progress of the reaction was monitored by TLC (petroleum ether: ethyl acetate = 7:3 as eluent). After completion of the reaction, the mixture was heated to solubilize the products and the catalyst removed by filtration. The filtrate was concentrated under reduced pressure, and the crude product obtained was recrystallized from ethanol to afford pure products 4(a–h).

4.3.1. Spectroscopic Data of 2-Amino-4-(2-chlorophenyl)-5,6,7,8-tetrahydro-7,7-dimethyl-5-oxo-4 H-chromene-3-carbonitrile (4g)²⁵

IR (KBr, ν_{max}): 3307, 2964, 2191, 1677, 1443, 769 cm⁻¹. ¹H NMR (300 MHz, CDCl₃) δ: 1.11 (s, 3H), 1.21 (s, 3H), 2.20 (s, 2H), 2.45 (s, 2H), 3.70 (s, 2H, NH), 4.63 (s, 1H), 7.11–7.12 (m, 2H, Ar-H), 7.19–7.26 (m, 1H, Ar-H), 7.30–7.33 (dd, 1H, Ar-H).

4.4 TG-DTA Analysis

Figure 1 illustrates the thermal analysis of the polyaniline and polyaniline/SiO₂ catalyst. The first weight loss occurs at low

**Figure 1** TG-DTA pattern of (a) polyaniline (b) 10 wt % polyaniline/SiO₂.

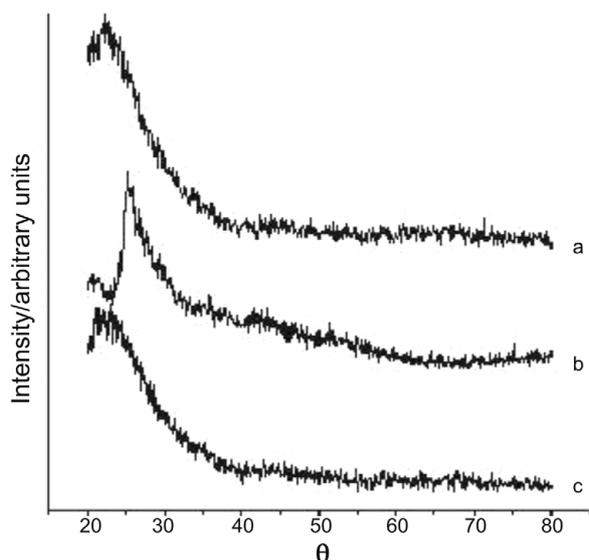


Figure 2 XRD pattern of (a) SiO_2 (b) polyaniline (c) 10 wt % polyaniline/ SiO_2 .

temperature (140 °C) for the removal of water from the polymer materials. The second weight loss was observed at 200 °C and corresponds to the degradation and decomposition of the polymer backbone. However, complete decomposition occurs between 350 °C for the polyaniline chain as shown in Fig. 1(a). Fig. 1(b) shows the thermal decomposition of polyaniline supported on SiO_2 . From this it can be seen that the thermal stability of polyaniline/ SiO_2 materials has noticeably improved, which may be due to the strong interaction between polyaniline and SiO_2 .

4.5 XRD Analysis

Figure 2(a–c) shows the XRD pattern of the synthesized materials. Figure 2(a) shows a broad peak at 2θ (21.98°) corresponding to the amorphous nature of silica.³⁵ Figure 2(b) shows the broad peak at 2θ (25.13°) which are characteristic of the polyaniline.³⁶ Finally, Fig. 2(c) indicates a broad peak at 2θ (22.18°) for 10 wt % polyaniline/ SiO_2 ; the peak was slightly shifted due to the addition of polyaniline into the mesoporous silica.

4.6 SEM Analysis

Figure 3(a–c) shows the surface morphology of the synthesized materials. Figure 3(a) shows good agglomeration of the particles of mesoporous silica which are spherical in shape, while a fibrous or globular morphology was observed in Fig. 3(b) which is the characteristic of polyaniline.³⁷ Figure 3(c) shows some porosity – this may be due to the insertion of 10 wt % polyaniline on the surface of SiO_2 . Finally, from the SEM micrograph it can be concluded that, the polyaniline addition clearly shows alteration in morphology, which helps to generate the porous materials and that the porosity may increase the catalytic activity of the material.

4.7 FT-IR Analysis

Figure 4(a–c) shows the FT-IR spectra of the synthesized materials. Figure 4(a) shows a peak at 3477 cm^{-1} which is due to the Si-OH stretching vibration, 1627 cm^{-1} for the Si-OH bending mode, 1080 cm^{-1} for Si-O stretching vibration and 815 cm^{-1} due to the Si-O-Si bending vibration mode. Figure 4(b–c) shows the FT-IR spectra of the pure polyaniline and 10 wt % polyaniline/ SiO_2 , respectively. The characteristic peaks of the polyaniline at

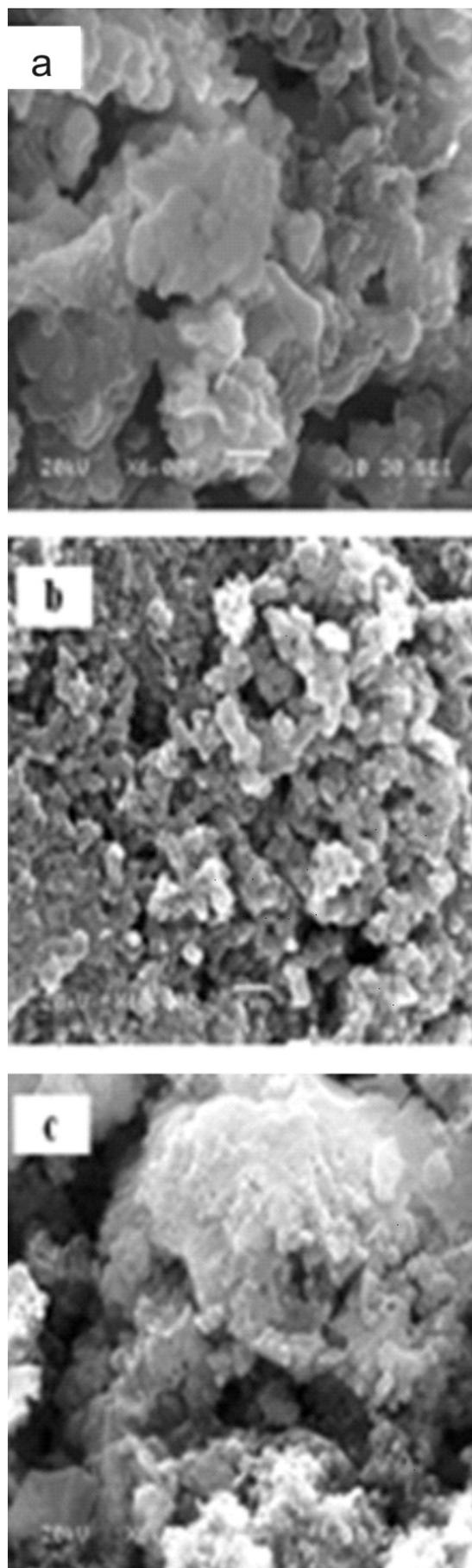


Figure 3 SEM image of (a) SiO_2 (b) polyaniline (c) 10 wt % polyaniline/ SiO_2 .

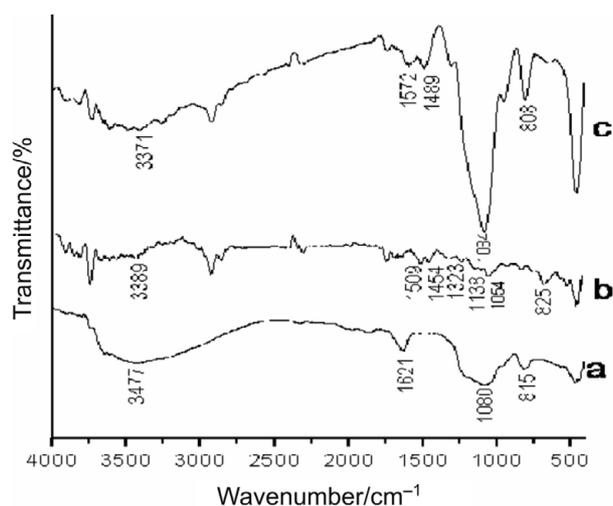


Figure 4 FT-IR spectra of (a) SiO₂ (b) polyaniline (c) 10 wt % polyaniline/SiO₂.

3389 and 3371 cm⁻¹ is attributed to N–H stretching, 1572 and 1509 cm⁻¹ is due to C=C stretching mode of the quinoid rings, 1489 and 1454 cm⁻¹ due to C=C stretching vibration of benzenoid rings, 1323 and 1309 cm⁻¹ for C–N stretching vibration, 1138 cm⁻¹ for N=Q=N, where Q represents the quinoid ring, peaks at 825 and 808 cm⁻¹ due to aromatic C–H bending mode of 1,4-disubstituted benzene ring. Figure 4(c) shows a peak at 1084 cm⁻¹ due the presence of silica.

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