available at www.sciencedirect.com

journal homepage: www.elsevier.com/locate/chnjc

Article

Silica-bonded *N*-propylpiperazine sodium *n*-propionate as recyclable catalyst for synthesis of 4*H*-pyran derivatives

Khodabakhsh Niknam ^{a,*}, Nassim Borazjani ^a, Reza Rashidian ^a, Abbas Jamali ^b^a Department of Chemistry, Faculty of Sciences, Persian Gulf University, Bushehr 75169, Iran^b Persian Gulf Research and Studies Center, Persian Gulf University, Bushehr 75169, Iran

ARTICLE INFO

Article history:

Received 30 June 2013

Accepted 21 August 2013

Published 20 December 2013

Keywords:

Silica-bonded *N*-propylpiperazine
sodium *n*-propionate

Heterogeneous solid base catalyst

Aldehyde

4*H*-Pyran derivative

Malononitrile

ABSTRACT

Silica-bonded *N*-propylpiperazine sodium *n*-propionate (SBPPSP) was found to act as an efficient solid base for the preparation of a series of 4*H*-benzo[*b*]pyran derivatives. SBPPSP was used as a recyclable heterogeneous solid base catalyst for the synthesis of 3,4-dihydropyrano[*c*]chromenes, 2-amino-4*H*-pyrans, 1,4-dihydropyrano[2,3-*c*]pyrazoles, and 2-amino-4*H*-benzo[*e*]-chromenes via the condensation reaction of dimedone, ethyl acetoacetate, 3-methyl-1-phenyl-1*H*-pyrazol-5(4*H*)-one, and α -naphthol, respectively, with aromatic aldehydes and malononitrile in refluxing aqueous ethanol. The heterogeneous solid base showed similar efficiency when reused in consecutive reactions.

© 2013, Dalian Institute of Chemical Physics, Chinese Academy of Sciences.
Published by Elsevier B.V. All rights reserved.

1. Introduction

The development of environmentally benign, efficient, and economical methods for the synthesis of biologically interesting compounds remains a significant challenge in synthetic chemistry. Multi-component reactions have become very popular in the discovery of biologically active novel compounds because of simple experimentation, atom economy, and high yields of the products [1].

2-Amino-4*H*-pyran derivatives represent an important class of compounds. They are often used in cosmetics, pigments, and as potentially biodegradable agrochemicals [2,3]. Polyfunctionalized 4*H*-pyrans also constitute a structural unit of many natural products [4,5] and biologically interesting compounds that possess various pharmacological activities [6], such as antiallergic [2], antitumor [7], and antibacterial properties [8–10]. 4*H*-Pyran derivatives are also potential calcium channel antagonists [11] and are structurally similar to biologically active

1,4-dihydropyridines.

Base-catalyzed condensation and addition reactions are important in the industrial production of drugs, fragrances, and chemical intermediates [12–17]. In addition, solid base catalysts are also used particularly for asymmetric organic syntheses [18,19], other organic syntheses [20–23], and characterization of active centers [24]. The potential uses of microporous and mesoporous base catalysts in fine chemical production are very promising [25]. These heterogeneous catalysts are known to suppress side reactions, which include self-condensation and oligomerization, resulting in better selectivity and product yield. This approach also avoids the complex neutralization and separation steps needed to recover the homogeneous base catalysts from the reaction mixture. Heterogeneous catalysts hold advantages over conventional homogeneous catalysts because they can be easily recovered from the reaction mixture by simple filtration and can be reused after activation, thereby making the process more economically viable. Recently, we

* Corresponding author. Tel: +98-771-4541494; Fax: +98-771-4545188; E-mail: niknam@pgu.ac.ir, khniknam@gmail.com

DOI: 10.1016/S1872-2067(12)60693-7 | http://www.sciencedirect.com/science/journal/18722067 | Chin. J. Catal., Vol. 34, No. 12, December 2013

Fig. 1. Proposed structure for SBPPSP and SBPP.

prepared silica-bonded *N*-propylpiperazine sodium *n*-propionate (SBPPSP) as a solid base catalyst for the synthesis of 3,4-dihydropyrano[*c*]chromenes [26] (Fig. 1). In addition, silica-bonded *N*-propylpiperazine (SBPP) and SBPPSP were used as support to immobilized of Pd nanoparticles for catalyzing C–C bond formation in Heck, Suzuki, and Sonogashira couplings, and in cyanation reactions [27–29]. We report here the application of SBPPSP as a heterogeneous and recyclable solid base catalyst for the preparation of a series of 4*H*-benzo[*b*]pyran derivatives (Scheme 1).

2. Experimental

2.1. General

Chemicals were purchased from Fluka, Merck, and Aldrich. All products were characterized by comparison of their infrared (IR), ^1H nuclear magnetic resonance (NMR), and ^{13}C NMR spectroscopic data and their melting points (mp) with the reported values [24–66]. SBPP was prepared according to previously reported procedures [26,30].

2.2. Catalyst preparation

2.2.1. Preparation of silica-bonded propylpiperazine methyl *N*-propionate (SBPPMP)

To a magnetically stirred mixture of 3-piperazine-*N*-propylsilica (25 g) in methanol (50 mL), methyl acrylate (25 mL) was added and heated at 40–50 °C for 48 h under N_2 . The mixture was filtered and washed with methanol (2×50 mL) and dried for 8 h under vacuum to afford SBPPMP as a white powder (26.6 g). Elemental analysis: C 13.47%, H 2.28%, and N 2.18%.

2.2.2. Preparation of SBPPSP

A magnetically stirred mixture of SBPPMP (26.6 g) was treated with HCl (0.5 mol/L, 50 mL). The mixture was filtered and dried overnight under vacuum [26]. Subsequently, the mixture was treated with saturated NaHCO_3 solution (50 mL) for 2 h. Then the mixture was filtered and dried overnight under vacuum to afford SBPPSP as a white powder (26.7 g). Elemental analysis: C 13.72%, H 2.30%, and N 2.78% [26].

The pH of the prepared SBPPSP was determined using a pH-ISE conductivity titration controller (Denver Instrument Model 270). The pH was 10.82 for 0.1 g of the solid base at 25 °C [26].

2.3. General procedure for synthesis of 2-amino-5,6,7,8-tetrahydro-4*H*-chromenes

To a mixture of aromatic aldehyde (1 mmol), malonitrile (1 mmol), and dimedone (1 mmol) in 3 mL of aqueous ethanol (1:1), SBPPSP catalyst (0.05 g, 4.3 mol%) was added, and the mixture was refluxed for an appropriate time. After completion of the reaction, as indicated by thin-layer chromatography (TLC), ethanol (10 mL) was added, and the reaction mixture was filtered. The residue was washed with warm ethanol (3×5 mL) to separate the heterogeneous catalyst. After cooling, the crude product was precipitated and then purified by recrystal-

Scheme 1. Synthesis of 4*H*-pyran derivatives in the presence of SBPPSP.

lization from ethanol (95%). The recovered catalyst was dried and reused in further reactions.

2-Amino-7,7-dimethyl-5-oxo-4-phenyl-5,6,7,8-tetrahydro-4H-chromene-3-carbonitrile (**4a**). mp 224–226 °C (226–228 °C [9]). ¹H NMR (400 MHz, CDCl₃): δ 1.07 (s, 3H), 1.14 (s, 3H), 2.22 (d, 1H, *J* = 16.4 Hz), 2.28 (d, 1H, *J* = 16.4 Hz), 2.45–2.53 (m, 2H), 4.43 (s, 1H), 4.54 (s, 2H, NH₂), 7.20–7.33 (m, 5H). ¹³C NMR (100 MHz, CDCl₃): δ 27.71, 28.91, 32.22, 35.53, 40.70, 50.68, 114.09, 118.61, 127.18, 127.56, 128.62, 143.15, 157.44, 161.49, 195.83.

2-Amino-4-(4-bromophenyl)-7,7-dimethyl-5-oxo-5,6,7,8-tetrahydro-4H-chromene-3-carbonitrile (**4b**). mp 201–203 °C (201–203 °C [32]). ¹H NMR (400 MHz, CDCl₃): δ 1.25 (s, 3H), 1.27 (s, 3H), 2.19–2.29 (m, 2H), 2.47 (s, 2H), 4.40 (s, 1H), 4.63 (s, 2H), 7.14 (d, 2H, *J* = 8.0 Hz), 7.44 (d, 2H, *J* = 8.0 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 27.65, 28.90, 32.23, 35.18, 40.67, 50.61, 118.44, 121.03, 129.41, 131.73, 135.67, 142.86, 195.91.

2-Amino-4-(4-fluorophenyl)-7,7-dimethyl-5-oxo-5,6,7,8-tetrahydro-4H-chromene-3-carbonitrile (**4c**). mp 198–200 °C (210–211 °C [35]). ¹H NMR (400 MHz, CDCl₃): δ 1.05 (s, 3H), 1.14 (s, 3H), 2.22 (d, 1H, *J* = 16.4 Hz), 2.28 (d, 1H, *J* = 16.4 Hz), 2.47 (s, 2H), 4.42 (s, 1H), 4.58 (s, 2H), 7.00 (t, 2H, *J* = 8.4 Hz), 7.22–7.29 (m, 2H). ¹³C NMR (100 MHz, CDCl₃): δ 27.65, 28.89, 32.23, 34.93, 40.67, 50.65, 113.96, 115.35, 115.56, 118.50, 129.17, 129.25, 138.97, 157.46, 160.67, 161.48, 195.87.

2-Amino-4-(2,4-dichlorophenyl)-7,7-dimethyl-5-oxo-5,6,7,8-tetrahydro-4H-chromene-3-carbonitrile (**4d**). mp 114–116 °C (115–117 °C [32]). ¹H NMR (400 MHz, CDCl₃): δ 1.07 (s, 3H), 1.13 (s, 3H), 2.19 (d, 1H, *J* = 16.4 Hz), 2.26 (d, 1H, *J* = 16.4 Hz), 2.43–2.51 (m, 2H), 4.81 (s, 3H), 7.15–7.22 (m, 2H), 7.36 (d, 1H, *J* = 1.6 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 27.69, 28.91, 32.14, 33.56, 40.62, 50.53, 112.28, 118.40, 127.42, 130.00, 131.45, 133.45, 133.98, 138.48, 158.04, 162.61, 195.94.

2-Amino-4-(4-cyanophenyl)-7,7-dimethyl-5-oxo-5,6,7,8-tetrahydro-4H-chromene-3-carbonitrile (**4e**). mp 208–210 °C (209–211 °C [37]). ¹H NMR (400 MHz, CDCl₃): δ 1.03 (s, 3H), 1.13 (s, 3H), 2.19–2.29 (m, 2H), 2.40–2.48 (m, 2H), 4.47 (s, 1H), 4.64 (s, 2H), 7.38–7.48 (m, 2H), 7.58–7.64 (m, 2H). ¹³C NMR (100 MHz, CDCl₃): δ 27.56, 28.88, 32.16, 36.25, 50.50, 58.25, 110.32, 112.67, 118.81, 119.48, 128.61, 132.26, 149.82, 158.99, 162.79, 195.77.

2-Amino-4-(3-cyanophenyl)-7,7-dimethyl-5-oxo-5,6,7,8-tetrahydro-4H-chromene-3-carbonitrile (**4f**). mp 170–172 °C. ¹H NMR (400 MHz, CDCl₃): δ 1.05 (s, 3H), 1.14 (s, 3H), 2.22 (d, 1H, *J* = 16.4 Hz), 2.28 (d, 1H, *J* = 16.4 Hz), 2.45–2.55 (m, 2H), 4.47 (s, 1H), 4.75 (s, 2H), 7.41–7.45 (m, 1H), 7.52–7.59 (m, 3H). ¹³C NMR (100 MHz, CDCl₃): δ 27.79, 28.75, 32.28, 35.49, 40.65, 50.56, 112.71, 113.16, 118.21, 118.88, 129.40, 130.93, 131.23, 144.76, 157.82, 162.12, 195.81. Elemental analysis for C₁₉H₁₇N₃O₂: C, 71.46; H, 5.37; N, 13.16; found: C, 71.20; H, 5.47; N, 12.96.

2-Amino-7,7-dimethyl-5-oxo-4-m-tolyl-5,6,7,8-tetrahydro-4H-chromene-3-carbonitrile (**4g**). mp 198–200 °C. ¹H NMR (400 MHz, CDCl₃): δ 0.97 (s, 3H), 1.13 (s, 3H), 2.16 (s, 3H), 2.25 (d, 1H, *J* = 16.0 Hz), 2.32 (d, 1H, *J* = 16.0 Hz), 2.58 (s, 2H), 4.31 (s, 1H), 6.76 (s, 2H, NH₂), 7.17 (d, 1H, *J* = 7.6 Hz), 7.34 (s, 1H), 7.39 (d, 1H, *J* = 7.2 Hz), 7.73–7.80 (m, 1H). ¹³C NMR (100 MHz, CDCl₃): δ 20.29, 27.29, 28.91, 32.28, 36.08, 50.47, 58.82, 113.25, 120.22, 126.75, 128.82, 132.97, 145.29, 158.94, 162.91, 196.17.

Elemental analysis for C₁₉H₂₀N₂O₂: C, 74.00; H, 6.54; N, 9.08; found: C, 73.73; H, 6.65; N, 8.92.

2-Amino-4-(4-isopropyl-phenyl)-7,7-dimethyl-5-oxo-5,6,7,8-tetrahydro-4H-chromene-3-carbonitrile (**4h**). mp 198–200 °C. ¹H NMR (400 MHz, CDCl₃): δ 0.99 (s, 3H), 1.11–1.15 (s, 9H), 2.26 (d, 1H, *J* = 16.0 Hz), 2.31 (d, 1H, *J* = 16.0 Hz), 2.53–2.62 (m, 2H), 2.72–2.80 (m, 1H), 4.23 (s, 1H), 6.98 (s, 2H, NH₂), 7.01 (d, 2H, *J* = 8.0 Hz), 7.24 (d, 2H, *J* = 8.0 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 22.77, 23.46, 26.29, 28.31, 31.88, 35.08, 50.17, 58.42, 113.11, 120.12, 126.15, 126.84, 142.97, 146.29, 158.94, 162.41, 195.67. Elemental analysis for C₂₁H₂₄N₂O₂: C, 74.97; H, 7.19; N, 8.33; found: C, 74.71; H, 7.30; N, 8.07.

2-Amino-7,7-dimethyl-5-oxo-4-(3,4,5-trimethoxy-phenyl)-5,6,7,8-tetrahydro-4H-chromene-3-carbonitrile (**4i**). mp 171–173 °C. ¹H NMR (400 MHz, CDCl₃): δ 1.10 (s, 3H), 1.14 (s, 3H), 2.25–2.32 (m, 2H), 2.44–2.54 (m, 2H), 3.81 (s, 3H), 3.84 (s, 6H), 4.35 (s, 1H), 4.54 (s, 2H), 6.43 (s, 2H). ¹³C NMR (100 MHz, CDCl₃): δ 27.34, 29.15, 32.12, 35.75, 40.65, 50.62, 56.07, 60.74, 62.81, 104.50, 113.71, 118.90, 136.88, 139.17, 153.19, 157.68, 161.92, 196.11. Elemental analysis for C₂₁H₂₄N₂O₅: C, 65.61; H, 6.29; N, 7.29; found: C, 65.36; H, 6.39; N, 7.02.

2-Amino-4-(4-dimethylamino-phenyl)-7,7-dimethyl-5-oxo-5,6,7,8-tetrahydro-4H-chromene-3-carbonitrile (**4j**). mp 201–203 °C (202–204 °C [32]). ¹H NMR (400 MHz, CDCl₃): δ 1.05 (s, 3H), 1.10 (s, 3H), 2.19–2.27 (m, 2H), 2.42–2.48 (m, 2H), 2.91 (s, 6H), 4.33 (s, 1H), 4.44 (s, 2H), 6.64 (d, 2H, *J* = 8.0 Hz), 7.08 (d, 2H, *J* = 8.0 Hz). ¹³C NMR (100 MHz, CDCl₃ and DMSO-*d*₆): δ 27.52, 29.02, 32.12, 34.85, 50.73, 60.37, 112.46, 114.05, 120.16, 128.16, 132.53, 149.43, 158.53, 161.66, 195.88.

2.4. General procedure for synthesis of 2-amino-4H-pyrans

To a mixture of aromatic aldehyde (1 mmol), malonitrile (1 mmol), and ethyl acetoacetate (1 mmol) in 3 mL of aqueous ethanol (1:1), catalyst SBPPSP (0.05 g, 4.3 mol%) was added, and the mixture was refluxed for an appropriate time. After completion of the reaction, as indicated by TLC, ethanol (10 mL) was added, and the reaction mixture was filtered. The residue was washed with warm ethanol (3 × 5 mL) to separate the heterogeneous catalyst. After cooling, the crude product was precipitated and then purified by recrystallization from ethanol (95%). The recovered catalyst was dried and reused in subsequent reactions.

6-Amino-4-(4-chloro-phenyl)-5-cyano-2-methyl-4H-pyran-3-carboxylic acid ethyl ester (**5a**). mp 170–172 °C (172–174 °C [43]). ¹H NMR (400 MHz, CDCl₃): δ 1.11 (t, 3H, *J* = 7.2 Hz), 2.42 (s, 3H), 4.02–4.1 (m, 2H), 4.52 (s, 1H), 4.71 (s, 2H), 7.35 (d, 2H, *J* = 8.4 Hz), 7.63 (d, 2H, *J* = 8.4 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 13.95, 18.51, 38.30, 60.82, 61.69, 107.57, 118.81, 128.76, 128.95, 132.95, 142.43, 157.12, 157.59, 165.70.

6-Amino-4-(3-chloro-phenyl)-5-cyano-2-methyl-4H-pyran-3-carboxylic acid ethyl ester (**5b**). mp 155–156 °C (153–156 °C [43]). ¹H NMR (400 MHz, CDCl₃): δ 1.14 (t, 3H, *J* = 7.2 Hz), 2.40 (s, 3H), 4.03–4.12 (m, 2H), 4.45 (s, 1H), 4.59 (s, 2H), 7.16 (d, 2H, *J* = 8.4 Hz), 7.29 (d, 2H, *J* = 8.4 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 14.24, 18.58, 39.77, 57.63, 60.64, 107.88, 114.31, 114.45, 118.30, 120.28, 129.80, 146.70, 156.75, 157.87, 159.06, 165.96.

6-Amino-4-(3-bromophenyl)-5-cyano-2-methyl-4*H*-pyran-3-carboxylic acid ethyl ester (**5c**). mp 166–167 °C. ¹H NMR (400 MHz, CDCl₃): δ 1.15 (t, 3H, *J* = 7.2 Hz), 2.41 (s, 3H), 4.01–4.15 (m, 2H), 4.44 (s, 1H), 4.62 (s, 2H), 7.17–7.22 (m, 2H), 7.34 (s, 1H), 7.38 (dt, 1H, *J* = 7.2, 1.6 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 13.96, 18.56, 38.60, 60.86, 61.67, 107.42, 118.67, 122.67, 126.47, 130.17, 130.41, 130.65, 146.15, 157.37, 157.63, 165.57. Elemental analysis for C₁₆H₁₅BrN₂O₃: C, 52.91; H, 4.16; Br, 22.00; N, 7.71; found: C, 52.69; H, 4.30; N, 7.51.

6-Amino-5-cyano-2-methyl-4-(3-nitrophenyl)-4*H*-pyran-3-carboxylic acid ethyl ester (**5d**). mp 182–184 °C (182–183 °C [43]). ¹H NMR (400 MHz, CDCl₃): δ 1.15 (t, 3H, *J* = 7.2 Hz), 2.45 (s, 3H), 4.04–4.12 (m, 2H), 4.61 (s, 1H), 4.67 (s, 2H), 7.52 (t, 1H, *J* = 8.0 Hz), 7.61 (d, 1H, *J* = 7.6 Hz), 8.08–8.09 (m, 1H), 8.14 (dd, 1H, *J* = 8.2, 1.2 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 13.96, 18.71, 38.78, 61.02, 106.97, 118.41, 122.46, 122.60, 129.57, 134.08, 146.13, 148.52, 157.02, 158.01, 165.31.

6-Amino-5-cyano-2-methyl-4-(4-nitrophenyl)-4*H*-pyran-3-carboxylic acid ethyl ester (**5e**). mp 183–185 °C (180–183 °C [43]). ¹H NMR (400 MHz, CDCl₃): δ 1.13 (t, 3H, *J* = 6.8 Hz), 2.44 (s, 3H), 4.04–4.09 (m, 2H), 4.59 (s, 1H), 4.70 (s, 2H), 7.41 (d, 2H, *J* = 8.8 Hz), 8.20 (d, 2H, *J* = 8.4 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 13.97, 18.68, 38.81, 60.80, 61.03, 106.77, 118.39, 124.05, 128.47, 147.07, 151.15, 157.76, 158.12, 165.32.

6-Amino-5-cyano-2-methyl-4-(4-trifluoromethyl-phenyl)-4*H*-pyran-3-carboxylic acid ethyl ester (**5f**). mp 182–184 °C. ¹H NMR (400 MHz, CDCl₃): δ 1.12 (t, 3H, *J* = 7.2 Hz), 2.42 (s, 3H), 4.03–4.11 (m, 2H), 4.54 (s, 1H), 4.65 (s, 2H), 7.35 (d, 2H, *J* = 8.0 Hz), 7.58 (d, 2H, *J* = 8.0 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 13.90, 18.56, 38.72, 60.89, 61.33, 107.26, 118.67, 122.76, 125.48, 125.59, 125.63, 125.67, 129.26, 129.59, 147.81, 157.61, 157.73, 165.54. Elemental analysis for C₁₇H₁₅F₃N₂O₃: C, 57.96; H, 4.29; F, 16.18; N, 7.95; found: C, 57.69; H, 4.41; N, 7.74.

6-Amino-5-cyano-2-methyl-4-(3-tolyl)-4*H*-pyran-3-carboxylic acid ethyl ester (**5g**). mp 181–183 °C. ¹H NMR (400 MHz, CDCl₃): δ 1.13 (t, 3H, *J* = 7.2 Hz), 2.35 (s, 3H), 2.40 (s, 3H), 4.02–4.11 (m, 2H), 4.43 (s, 1H), 4.55 (s, 2H), 7.01–7.06 (m, 3H), 7.20 (t, 1H, *J* = 7.6 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 13.91, 18.45, 21.51, 38.69, 60.67, 62.25, 108.06, 119.10, 124.67, 128.25, 138.11, 143.72, 156.70, 157.58, 165.99. Elemental analysis for C₁₇H₁₈N₂O₃: C, 68.44; H, 6.08; N, 9.39; found: C, 68.19; H, 6.20; N, 9.16.

6-Amino-5-cyano-4-(4-isopropyl-phenyl)-2-methyl-4*H*-pyran-3-carboxylic acid ethyl ester (**5h**). mp 176–177 °C. ¹H NMR (400 MHz, CDCl₃): δ 1.12 (t, 3H, *J* = 7.2 Hz), 1.29 (d, 6H, *J* = 6.0 Hz), 2.38 (s, 3H), 2.85–2.92 (m, 1H), 4.02–4.12 (m, 2H), 4.44 (s, 1H), 4.55 (s, 2H), 7.13–7.16 (m, 4H). ¹³C NMR (100 MHz, CDCl₃): δ 13.90, 18.43, 23.96, 38.30, 60.66, 62.35, 108.24, 119.18, 126.61, 127.39, 141.14, 147.65, 156.61, 157.60, 166.03. Elemental analysis for C₁₉H₂₂N₂O₃: C, 69.92; H, 6.79; N, 8.58; found: C, 69.66; H, 6.90; N, 8.39.

6-Amino-5-cyano-2-methyl-4-thiophen-2-yl-4*H*-pyran-3-carboxylic acid ethyl ester (**5j**). mp 203–205 °C. ¹H NMR (400 MHz, CDCl₃): δ 1.24 (t, 3H, *J* = 7.2 Hz), 2.38 (s, 3H), 4.14–4.22 (m, 2H), 4.56 (s, 2H), 4.85 (s, 1H), 6.93–6.95 (m, 2H), 7.19 (dd, 1H, *J* = 4.0, 2.0 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 14.03, 18.50, 33.68, 60.93, 62.22, 108.27, 118.72, 124.58, 126.90, 148.17, 157.02,

157.96, 165.64. Elemental analysis for C₁₄H₁₄N₂O₃S: C, 57.92; H, 4.86; N, 9.65; S, 11.04; found: C, 57.67; H, 4.96; N, 9.46.

2.5. General procedure for synthesis of dihydropyrano[2,3-*c*]pyrazoles

To a mixture of aromatic aldehyde (1 mmol), malonitrile (1 mmol), and 3-methyl-1-phenyl-1*H*-pyrazol-5(4*H*)-one (1 mmol) in 3 mL of aqueous ethanol (1:1), catalyst SBPPSP (0.05 g, 4.3 mol%) was added, and the mixture was refluxed for an appropriate time. After completion of the reaction, as indicated by TLC, ethanol (10 mL) was added and the reaction mixture was filtered. The residue was washed with warm ethanol (3 × 5 mL) to separate the heterogeneous catalyst. After cooling, the crude product was precipitated and then purified by recrystallization from ethanol (95%). The recovered catalyst was dried and reused in subsequent reactions.

6-Amino-3-methyl-1,4-diphenyl-1,4-dihydro-pyrano[2,3-*c*]pyrazol-5-carbonitrile (**6a**). mp 170–171 °C (168–170 °C [47]). ¹H NMR (400 MHz, CDCl₃): δ 1.92 (s, 3H), 4.69 (s, 1H), 4.71 (s, 2H, NH₂), 7.27–7.40 (m, 6H), 7.49 (t, 2H, *J* = 7.8 Hz), 7.68 (d, 2H, *J* = 8.0 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 12.94, 37.44, 63.88, 98.36, 119.14, 121.22, 126.80, 127.62, 127.91, 128.83, 129.31, 137.57, 142.00, 143.84, 146.46, 158.17.

6-Amino-4-(4-chlorophenyl)-3-methyl-1-phenyl-1,4-dihydro-pyrano[2,3-*c*]pyrazol-5-carbonitrile (**6b**). mp 174–176 °C (174–177 °C [52]). ¹H NMR (400 MHz, CDCl₃): δ 1.92 (s, 3H), 4.68 (s, 1H), 4.74 (s, 2H, NH₂), 7.22 (d, 2H, *J* = 8.4 Hz), 7.33–7.37 (m, 3H), 7.49 (t, 2H, *J* = 7.8 Hz), 7.67 (d, 2H, *J* = 8.0 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 12.97, 36.91, 63.36, 97.87, 118.95, 121.25, 126.92, 129.06, 129.28, 129.34, 133.44, 137.45, 140.57, 143.80, 146.28, 158.23.

6-Amino-4-(2,4-dichlorophenyl)-3-methyl-1-phenyl-1,4-dihydro-pyrano[2,3-*c*]pyrazol-5-carbonitrile (**6c**). mp 183–185 °C (182–184 °C [47]). ¹H NMR (400 MHz, CDCl₃): δ 1.92 (s, 3H), 4.78 (s, 2H, NH₂), 5.29 (s, 1H), 7.17 (d, 1H, *J* = 8.4 Hz), 7.26–7.28 (m, 1H), 7.35 (t, 1H, *J* = 7.2 Hz), 7.46–7.51 (m, 3H), 7.67 (d, 2H, *J* = 8.0 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 12.77, 33.53, 61.98, 97.58, 118.62, 121.28, 126.97, 128.04, 129.35, 129.68, 131.49, 133.95, 137.41, 137.86, 143.95, 146.04, 158.84.

6-Amino-4-(4-bromophenyl)-3-methyl-1-phenyl-1,4-dihydro-pyrano[2,3-*c*]pyrazol-5-carbonitrile (**6d**). mp 182–184 °C (176–177 °C [49]). ¹H NMR (400 MHz, CDCl₃): δ 1.92 (s, 3H), 4.67 (s, 1H), 4.73 (s, 2H, NH₂), 7.17 (d, 2H, *J* = 8.0 Hz), 7.35 (t, 1H, *J* = 7.4 Hz), 7.48–7.53 (m, 4H), 7.67 (d, 2H, *J* = 7.6 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 12.98, 36.98, 63.31, 97.78, 118.92, 121.26, 121.60, 126.93, 129.34, 129.63, 132.01, 137.45, 141.08, 146.28, 158.22.

6-Amino-4-(4-fluorophenyl)-3-methyl-1-phenyl-1,4-dihydro-pyrano[2,3-*c*]pyrazol-5-carbonitrile (**6e**). mp 170–171 °C (167–168 °C [47]). ¹H NMR (400 MHz, CDCl₃): δ 1.91 (s, 3H), 4.69 (s, 1H), 4.73 (s, 2H, NH₂), 7.07 (t, 2H, *J* = 8.6 Hz), 7.24–7.28 (m, 2H), 7.35 (t, 1H, *J* = 7.4 Hz), 7.49 (t, 2H, *J* = 7.8 Hz), 7.67 (d, 2H, *J* = 8.0 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 12.94, 36.78, 63.69, 98.15, 115.86, 119.01, 121.24, 126.88, 129.33, 129.54, 137.49, 143.77, 146.32, 158.14, 162.17 (d, *J*_{C-F} = 244.0 Hz).

6-Amino-3-methyl-4-(3-nitrophenyl)-1-phenyl-1,4-dihydro-

pyrano[2,3-*c*]-pyrazol-5-carbonitrile (**6f**). mp 190–191 °C (190–192 °C [52]). ¹H NMR (400 MHz, CDCl₃): δ 1.92 (s, 3H), 4.84 (s, 3H, CH and NH₂), 7.37 (t, 1H, *J* = 7.4 Hz), 7.51 (t, 2H, *J* = 7.6 Hz), 7.60 (t, 1H, *J* = 8.0 Hz), 7.67–7.70 (m, 3H), 8.14 (s, 1H), 8.21 (d, 1H, *J* = 8.0 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 13.01, 37.38, 62.11, 97.21, 118.76, 121.42, 122.87, 127.11, 129.37, 129.89, 134.17, 137.33, 144.49, 145.92, 148.76, 158.75.

6-Amino-3-methyl-4-(4-nitrophenyl)-1-phenyl-1,4-dihydro-pyrano[2,3-*c*]-pyrazol-5-carbonitrile (**6g**). mp 194–196 °C (195–197 °C [52]). ¹H NMR (400 MHz, CDCl₃): δ 1.92 (s, 3H), 4.83 (s, 3H, CH and NH₂), 7.37 (t, 1H, *J* = 7.4 Hz), 7.47–7.53 (m, 4H), 7.78 (d, 2H, *J* = 8.0 Hz), 8.27 (d, 2H, *J* = 8.4 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 12.98, 37.33, 62.26, 97.07, 118.58, 121.35, 124.28, 127.16, 128.88, 129.40, 137.30, 143.83, 146.00, 147.46, 149.19, 158.56.

6-Amino-4-(3,4-dimethoxyphenyl)-3-methyl-1-phenyl-1,4-dihydro-pyrano[2,3-*c*]-pyrazol-5-carbonitrile (**6h**). mp 167–169 °C (193–195 °C [47]). ¹H NMR (400 MHz, CDCl₃): δ 1.91 (s, 3H), 3.85 (s, 3H), 3.87 (s, 3H), 4.62 (s, 1H), 4.73 (s, 2H, NH₂), 6.73 (d, 1H, *J* = 1.6 Hz), 6.79–6.85 (m, 2H), 7.31 (t, 1H, *J* = 8.0 Hz), 7.45 (t, 2H, *J* = 8.0 Hz), 7.66 (d, 2H, *J* = 8.4 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 12.98, 37.06, 55.86, 55.98, 63.92, 98.29, 110.82, 111.12, 119.22, 120.18, 121.05, 126.71, 129.28, 134.56, 137.57, 143.80, 146.52, 148.41, 149.20, 158.02.

6-Amino-3-methyl-4-naphthalen-2-yl-1-phenyl-1,4-dihydro-pyrano[2,3-*c*]-pyrazol-5-carbonitrile (**6i**). mp 157–159 °C. ¹H NMR (400 MHz, CDCl₃): δ 1.89 (s, 3H), 4.81 (s, 2H, NH₂), 4.86 (s, 1H), 7.33–7.37 (m, 2H), 7.48–7.54 (m, 4H), 7.71 (d, 2H, *J* = 7.6 Hz), 7.77 (s, 1H), 7.86 (d, 2H, *J* = 8.4 Hz). ¹³C NMR (100 MHz, CDCl₃): δ 12.97, 37.67, 60.46, 98.23, 119.21, 121.20, 125.66, 126.06, 126.33, 126.71, 126.81, 127.76, 128.01, 128.96, 129.33, 132.92, 133.34, 137.58, 139.28, 143.90, 146.58, 158.33. Elemental analysis for C₂₄H₁₈N₄O: C, 76.17; H, 4.79; N, 14.81; found: C, 75.90; H, 4.91; N, 14.60.

6-Amino-4-(4-hydroxyphenyl)-3-methyl-1-phenyl-1,4-dihydro-pyrano[2,3-*c*]-pyrazol-5-carbonitrile (**6j**). mp 206–208 °C (206–207 °C [49]). ¹H NMR (500 MHz, DMSO-*d*₆): δ 1.78 (s, 3H), 4.55 (s, 1H), 6.71 (d, 2H, *J* = 7.8 Hz), 7.03 (d, 2H, *J* = 7.8 Hz), 7.10 (s, 2H, NH₂), 7.31 (t, 1H, *J* = 7.0 Hz), 7.48 (t, 2H, *J* = 7.3 Hz), 7.77 (d, 2H, *J* = 7.7 Hz), 9.31 (s, 1H). ¹³C NMR (125 MHz, DMSO-*d*₆): δ 13.45, 36.88, 59.68, 99.91, 116.07, 120.75, 120.96, 126.94, 129.62, 130.18, 134.79, 138.45, 144.65, 146.22, 157.15, 160.30.

2.6. General procedure for synthesis of 2-amino-3-cyano-4-aryl-4*H*-benzo[*e*]chromenes

To a mixture of aromatic aldehyde (1 mmol), malonitrile (1 mmol), and α-naphthol (1 mmol) in 3 mL of aqueous ethanol (1:1), catalyst SBPPSP (0.05 g, 4.3 mol%) was added, and the mixture was refluxed for an appropriate time. After completion of the reaction, as indicated by TLC, ethanol (10 mL) was added, and the reaction mixture was filtered. The residue was washed with warm ethanol (3 × 5 mL) to separate the heterogeneous catalyst. After cooling, the crude product was precipitated and then purified by recrystallization from ethanol (95%). The recovered catalyst was dried and reused in subsequent reactions.

2-Amino-4-phenyl-4*H*-benzo[*h*]chromene-3-carbonitrile (**7a**). mp 216–218 °C (210–211 °C [60]). ¹H NMR (400 MHz, DMSO-*d*₆): δ 4.91 (s, 1H), 7.11–7.34 (m, 8H), 7.57–7.67 (m, 3H), 7.90 (d, 1H, *J* = 8.0 Hz), 8.27 (d, 1H, *J* = 8.4 Hz). ¹³C NMR (100 MHz, DMSO-*d*₆): δ 56.72, 118.42, 121.03, 121.18, 123.24, 124.37, 126.71, 127.4, 128.15, 129.19, 133.16, 143.21, 146.19, 160.65.

2-Amino-4-(4-chloro-phenyl)-4*H*-benzo[*h*]chromene-3-carbonitrile (**7b**). mp 231–233 °C (232 °C [60]). ¹H NMR (400 MHz, DMSO-*d*₆): δ 4.97 (s, 1H), 7.11 (d, 1H, *J* = 8.8 Hz), 7.22 (s, 2H, NH₂), 7.28–7.31 (m, 2H), 7.38–7.41 (m, 2H), 7.58–7.68 (m, 3H), 7.91 (d, 1H, *J* = 8.0 Hz), 8.25 (d, 1H, *J* = 8.4 Hz). ¹³C NMR (100 MHz, DMSO-*d*₆): δ 56.29, 117.89, 120.85, 121.18, 123.20, 124.50, 126.57, 127.23, 127.36, 128.19, 129.18, 130.06, 132.02, 133.23, 143.22, 145.16, 160.63.

2-Amino-4-(2-chloro-phenyl)-4*H*-benzo[*h*]chromene-3-carbonitrile (**7c**). mp 234–236 °C (252–253 °C [63]). ¹H NMR (400 MHz, DMSO-*d*₆): δ 5.43 (s, 1H), 7.02 (d, 1H, *J* = 8.8 Hz), 7.23 (s, 2H, NH₂), 7.26–7.33 (m, 3H), 7.46–7.48 (m, 1H), 7.58–7.68 (m, 3H), 7.90 (d, 1H, *J* = 8.0 Hz), 8.26 (d, 1H, *J* = 8.4 Hz). ¹³C NMR (100 MHz, DMSO-*d*₆): δ 55.32, 117.06, 120.64, 121.21, 123.13, 124.57, 125.92, 127.35, 128.44, 129.35, 130.29, 131.70, 133.31, 142.66, 143.46, 160.35.

2-Amino-4-(4-bromophenyl)-4*H*-benzo[*h*]chromene-3-carbonitrile (**7d**). mp 240–242 °C (239–241 °C [65]). ¹H NMR (400 MHz, DMSO-*d*₆): δ 4.95 (s, 1H), 7.11 (d, 1H, *J* = 8.4 Hz), 7.22–7.24 (d, 4H), 7.525 (d, 2H, *J* = 8.8 Hz), 7.57–7.67 (m, 3H), 7.91 (d, 1H, *J* = 8.0 Hz), 8.25 (d, 1H, *J* = 8.0 Hz). ¹³C NMR (100 MHz, DMSO-*d*₆): δ 56.21, 117.81, 120.56, 120.86, 121.18, 123.21, 124.51, 126.57, 127.23, 127.36, 128.19, 130.44, 132.10, 133.24, 143.23, 145.58, 160.63.

2-Amino-4-(3-nitrophenyl)-4*H*-benzo[*h*]chromene-3-carbonitrile (**7e**). mp 213–215 °C (212 °C [62]). ¹H NMR (400 MHz, DMSO-*d*₆): δ 5.22 (s, 1H), 7.16 (d, 1H, *J* = 8.8 Hz), 7.35 (s, 2H, NH₂), 7.58–7.68 (m, 4H), 7.75 (d, 1H, *J* = 8.0 Hz), 7.90 (d, 1H, *J* = 8.0 Hz), 8.11–8.15 (m, 2H), 8.28 (d, 1H, *J* = 8.4 Hz). ¹³C NMR (100 MHz, DMSO-*d*₆): δ 19.02, 56.54, 117.25, 120.76, 121.26, 122.54, 123.22, 124.70, 126.40, 127.29, 128.18, 135.06, 143.40, 148.45, 160.91.

2-Amino-4-(4-nitrophenyl)-4*H*-benzo[*h*]chromene-3-carbonitrile (**7f**). mp 236–237 °C (240–242 °C [66]). ¹H NMR (400 MHz, DMSO-*d*₆): δ 5.17 (s, 1H), 7.12 (d, 1H, *J* = 8.8 Hz), 7.33 (s, 2H, NH₂), 7.56 (d, 2H, *J* = 8.8 Hz), 7.59–7.69 (m, 3H), 7.92 (d, 1H, *J* = 8.0 Hz), 8.21 (d, 2H, *J* = 8.4 Hz), 8.27 (d, 1H, *J* = 8.0 Hz). ¹³C NMR (100 MHz, DMSO-*d*₆): δ 55.65, 117.08, 120.67, 121.23, 123.22, 124.56, 124.69, 126.40, 127.32, 127.52, 128.21, 129.51, 133.38, 143.41, 146.96, 153.46, 160.81.

2-Amino-4-*p*-tolyl-4*H*-benzo[*h*]chromene-3-carbonitrile (**7g**). mp 204–205 °C (206–207 °C [63]). ¹H NMR (400 MHz, DMSO-*d*₆): δ 2.26 (s, 3H), 4.86 (s, 1H), 7.09–7.16 (m, 7H), 7.57–7.67 (m, 3H), 7.87–7.90 (m, 1H), 8.25 (d, 1H, *J* = 8.0 Hz). ¹³C NMR (100 MHz, DMSO-*d*₆): δ 56.81, 118.55, 121.02, 121.16, 123.21, 124.29, 126.75, 127.21, 128.07, 129.72, 131.17, 133.12, 136.72, 143.11, 143.27, 160.52.

2-Amino-4-(3,4,5-trimethoxy-phenyl)-4*H*-benzo[*h*]chromene-3-carbonitrile (**7h**). mp 182–184 °C (184–186 °C [65]). ¹H NMR (400 MHz, DMSO-*d*₆): δ 3.64 (s, 3H), 3.72 (s, 6H), 4.88 (s, 1H),

6.59 (s, 2H), 7.16 (s, 2H, NH₂), 7.21 (d, 1H, $J = 8.4$ Hz), 7.58–7.66 (m, 3H), 7.90 (d, 1H, $J = 8.0$ Hz), 8.25 (d, 1H, $J = 8.4$ Hz). ¹³C NMR (100 MHz, DMSO-*d*₆): δ 56.31, 56.36, 60.39, 79.12, 79.77, 105.41, 118.17, 121.04, 121.24, 123.22, 124.27, 126.67, 127.09, 128.16, 133.19, 136.86, 141.77, 142.99, 153.48, 160.71.

2-Amino-4-(4-hydroxy-phenyl)-4*H*-benzo[*h*]chromene-3-carbonitrile (**7i**). mp 245–247 °C (245–246 °C [63]). ¹H NMR (400 MHz, DMSO-*d*₆): δ 4.78 (s, 1H), 6.71 (d, 2H, $J = 8.4$ Hz), 7.04–7.11 (m, 5H), 7.55–7.66 (m, 3H), 7.89 (d, 1H, $J = 8.0$ Hz), 8.24 (d, 1H, $J = 8.4$ Hz), 9.34 (s, 1H, OH). ¹³C NMR (100 MHz, DMSO-*d*₆): δ 57.17, 115.18, 118.94, 121.14, 123.23, 124.22, 126.83, 127.08, 127.13, 128.14, 129.16, 133.06, 136.66, 143.02, 156.76, 160.43.

3. Results and discussion

The thermogravimetric analysis curve of SBPPSP shows the mass loss of organic materials during decomposition upon heating (Fig. 2). The initial mass loss from SBPPSP up to 130 °C is caused by removal of physically adsorbed solvent and surface hydroxyl groups. The mass loss of about 19.27% between 150 and 600 °C is attributed to the thermal decomposition of organic groups. This mass loss of organic components is equal to 0.87 mmol/g catalyst. It appears that the covalent connection of the catalyst to the silica support resulted in high thermal stability. This suggests that the catalyst should be useful in high temperature applications.

To study the surface morphology of the catalysts, scanning electron microscopy (SEM) images of SBPPSP and SBPP were recorded. As shown in Figs. 3 and 4, both samples showed an even distribution of piperazine on the surface of the silica gel. No conglomeration or layering of piperazine was observed.

3.1. Synthesis of 2-amino-5-oxo-5,6,7,8-tetrahydro-4*H*-chromenes

The conventional synthesis of 2-amino-5-oxo-5,6,7,8-tetrahydro-4*H*-chromenes involves the condensation of dimedone with aromatic aldehyde and malononitrile under reflux in acetic acid [31], or the bicomponent condensation of dimedone with α -cyanocinnamonnitriles in the presence of ethanolic piperidine [67]. Other effective methods include the use of microwave [68] or ultrasonic irradiation [69], or use of hexadecyltrimethyl ammonium bromide [70], triethylbenzylammonium chloride [71], KF-alumina [72], rare earth perfluorooctanoate [32], (*S*)-proline [33], amino-functionalized ionic liquids [34], tetrabutylammonium fluoride [35], silica-bonded *n*-propyl-4-aza-1-azoniabicyclo[2.2.2]octane chloride (SB-DABCO) [36], or well-ordered mesoporous silica nanoparticles [37] as catalyst in a one-pot reaction. However, most of these methods suffer from drawbacks such as low yield, long reaction time, harsh reaction conditions, tedious work-up procedures, or use of expensive catalysts.

Fig. 3. SEM images of SBPPSP.

Fig. 4. SEM images of SBNPP.

In most of the reported methods, the catalysts are not recyclable. Therefore, the development of an efficient, one-pot, chemoselective procedure for the synthesis of benzo[*b*]pyranes is of considerable interest. To study the effect of catalyst loading on the synthesis of 2-amino-5-oxo-5,6,7,8-tetrahydro-4*H*-chromenes, the condensation reaction of 4-bromobenzaldehyde, malononitrile, and dimedone was chosen as a model reaction. The results (Table 1) show clearly that silica-bonded piperazine derivatives are effective catalysts for this condensation and the optimal amount of SBPPSP was 0.05 g/mmol of aldehyde in refluxing aqueous ethanol (1:1). This condensation was carried out with low amounts of SBPPSP of 0.01 and 0.03 g, and the corresponding products were obtained in 50% and 80% yield, respectively (Table 1, entries 5 and 6).

This three-component condensation was also accomplished in the presence of SBPPSP in ethanol or water under reflux for longer reaction time and lower yield (Table 1, entries 1 and 2). Moreover, the model reaction was examined under solvent-free conditions at 100 °C and gave the corresponding product in 50% yield after 60 min (Table 1, entry 5). The model reaction was performed in the presence of SBPP under optimized conditions in refluxing aqueous ethanol and gave the product in 90% yield (Table 1, entry 8).

The synthesis of 2-amino-5-oxo-5,6,7,8-tetrahydro-4*H*-chromenes was achieved by the three-component condensation of an aromatic aldehyde, malononitrile, and dimedone in the presence of SBPPSP (0.05 g, 4.3 mol%) in refluxing aqueous

Fig. 2. Thermogravimetric curve for SBPPSP.

Table 1

Effect of catalyst and solvent on the condensation of 4-bromobenzaldehyde, malononitrile, and dimedone.

Entry	Catalyst	Catalyst loading (g)	Solvent/temperature (°C)	Time (min)	Isolated yield (%)
1	SBPPSP	0.05	Ethanol/reflux	30	90
2	SBPPSP	0.05	H ₂ O/reflux	70	90
3	SBPPSP	0.05	Ethanol/H ₂ O (1:1)/reflux	20	92
4	SBPPSP	0.05	Solvent-free/100	60	50
5	SBPPSP	0.01	Ethanol/H ₂ O (1:1)/reflux	60	50
6	SBPPSP	0.03	Ethanol/H ₂ O (1:1)/reflux	45	80
7	SBPPSP	0.07	Ethanol/H ₂ O (1:1)/reflux	15	94
8	SBPP	0.05	Ethanol/H ₂ O (1:1)/reflux	25	90

ethanol (Table 2). Thereafter, a series of 2-amino-5-oxo-5,6,7,8-tetrahydro-4H-chromene derivatives was prepared in refluxing aqueous ethanol from dimedone, malononitrile, and different aromatic aldehydes bearing electron-withdrawing or electron-donating groups. Benzaldehydes featuring electron-withdrawing groups such as 4-cyano (**1m**) and 3-cyano (**1l**) groups reacted under optimized conditions to give **4e** and **4f** in 90% and 91% yields, respectively (Table 2, entries 5 and 6). For electron-donating groups, benzaldehydes bearing 3-methyl (**1n**), 4-iso-propyl (**1p**), 3,4,5-trimethoxy (**1r**), or 4-*N,N*-dimethylamino (**1s**) groups were treated with malononitrile and dimedone under optimized conditions to give the corresponding products **4g**, **4h**, **4i**, and **4j** in high yields (Table 2, entries 7–10). The results clearly indicate that the reaction can tolerate a wide range of differently substituted aromatic aldehydes.

Table 2

SBPPSP-catalyzed synthesis of 2-amino-5-oxo-5,6,7,8-tetrahydro-4H-chromene derivatives.

Entry	Ar	Product	Time (min)	Isolated yield (%)
1	C ₆ H ₅ - (1a)	4a	25	90
2	4-BrC ₆ H ₄ - (1g)	4b	20	92, 92, 91, 90 ^a
3	4-FC ₆ H ₄ - (1h)	4c	20	90
4	2,4-(Cl) ₂ C ₆ H ₃ - (1e)	4d	20	92
5	4-(CN)C ₆ H ₄ - (1m)	4e	20	90
6	3-(CN)C ₆ H ₄ - (1l)	4f	15	91
7	3-MeC ₆ H ₄ - (1n)	4g	45	88
8	4-iso-PrC ₆ H ₄ - (1p)	4h	45	89
9	3,4,5-(CH ₃ O) ₃ C ₆ H ₂ - (1r)	4i	45	86
10	4-(Me) ₂ N-C ₆ H ₄ - (1s)	4j	45	87

Reaction conditions: dimedone 1 mmol, malononitrile 1 mmol, aldehyde 1 mmol, SBPPSP 0.05 g, H₂O:ethanol (1:1) 3 mL, reflux.

^a Recovered SBPPSP was used as catalyst.

The possible reuse of catalyst was examined using the reaction of malononitrile, 4-bromobenzaldehyde, and dimedone under optimized conditions. Upon completion, the reaction mixture was washed with warm ethanol (3 × 30 mL). The recovered catalyst was dried and reused in further reactions. The recycled catalyst could be reused three times without any additional treatment. No observation of appreciable loss in catalytic activity of SBPPSP was apparent (Table 2, entry 2).

3.2. Synthesis of 2-amino-4H-pyrans

2-Amino-4H-pyrans have been synthesized by cyclization of arylidenemalononitriles with β-dicarbonyl compounds in the presence of a base such as piperidine [38], morpholine, pyridine [39], triethylamine [40,41], MgO/La [42], sodium methoxide, 1,1,3,3-tetramethylguanidine, MgO [43], silica nanoparticles [44], or baker's yeast [45]. Most of these methods also involve the use of volatile solvents and require long reaction times (~12 h), and subsequent recovery of the catalyst is difficult.

2-Amino-4H-pyrans were synthesized by the three-component condensation reaction between ethyl acetoacetate, malononitrile, and aromatic aldehydes in the presence of SBPPSP (0.05 g) in refluxing aqueous ethanol (Table 3).

As shown in Table 3, aromatic aldehydes bearing electron-withdrawing or electron-donating groups were condensed with malononitrile and ethyl acetoacetate under optimized conditions in high yields. Benzaldehydes functionalized with electron-withdrawing groups such as 3-nitro (**1i**), 4-nitro (**1j**), and 4-trifluoromethyl (**1k**) groups reacted under optimized conditions to give **5d**, **5e**, and **5f** in 91%, 93%, and 90% yields, respectively, after 40 min (Table 3, entries 4–6). Benzaldehydes functionalized with electron-donating groups such as 3-methyl (**1n**) and 4-iso-propyl (**1p**) groups also reacted well under optimized conditions to give the corresponding products **5g** and **5h** in high yields (Table 3, entries 7 and 8). Heterocyclic aldehydes such as thiophene-2-carbaldehyde (**1v**) also gave the corresponding product in good yield (Table 3,

Table 3

SBPPSP-catalyzed synthesis of 2-amino-4H-pyran derivatives.

Entry	Ar	Product	Time (min)	Isolated yield (%)
1	4-ClC ₆ H ₄ - (1b)	5a	35	92, 91, 91, 89 ^a
2	3-ClC ₆ H ₄ - (1c)	5b	40	91
3	3-BrC ₆ H ₄ - (1f)	5c	40	91
4	3-O ₂ NC ₆ H ₄ - (1i)	5d	40	91
5	4-O ₂ NC ₆ H ₄ - (1j)	5e	40	93
6	4-CF ₃ C ₆ H ₄ - (1k)	5f	40	90
7	3-MeC ₆ H ₄ - (1n)	5g	45	89
8	4-iso-PrC ₆ H ₄ - (1p)	5h	50	88
9	2-Thiophenyl (1v)	5i	50	86

Reaction conditions: ethyl acetoacetate 1 mmol, malononitrile 1 mmol, aldehyde 1 mmol, SBPPSP 0.05 g, H₂O:ethanol (1:1) 3 mL, reflux.

^a Recovered SBPPSP was used as catalyst.

entry 9), indicating that the reaction can tolerate a wide range of differently substituted aromatic aldehydes. As shown in Table 3, the catalyst was recycled three times in the three-component condensation reaction of malononitrile, 4-chlorobenzaldehyde, and ethyl acetoacetate under optimized conditions (Table 3, entry 1).

3.3. Synthesis of pyrano[2,3-*c*]pyrazoles

The three-component, one-pot condensation of 3-methyl-1-phenyl-1*H*-pyrazol-5(4*H*)-one, aldehydes, and malononitrile for the construction of 1,4-dihydropyrano[2,3-*c*]pyrazole derivatives has been reported under different conditions [46–50]. However, most of the reported methods have their drawbacks. For example, hexadecyltrimethylammonium bromide catalyst is a harmful irritant that is dangerous to the environment [48], while the reuse of catalysts such as D,L-proline is not reported in a number of cases [49]. Heteropoly acids and silica-supported bases or acids have been reported for the synthesis of 1,4-dihydropyrano[2,3-*c*]pyrazole derivatives via multi-component condensation reactions [51–56].

The scope of this methodology was extended to the synthesis of pyrano[2,3-*c*]pyrazoles. Initially, a three-component condensation reaction of malononitrile, 4-chlorobenzaldehyde, and 3-methyl-1-phenyl-1*H*-pyrazol-5(4*H*)-one was investigated in the presence of SBPPSP in aqueous ethanol under reflux (Table 4). Substituted aromatic aldehydes featuring the electron-withdrawing 3-nitro (**1i**) or 4-nitro (**1j**) group, or the electron-donating 3,4-dimethoxy (**1q**) group reacted under optimized conditions to give **6f**, **6g**, and **6h** in 90%, 88%, and 90% yields, respectively (Table 4, entries 6–8). 2-Naphthalen carbaldehyde (**1t**) was converted under optimized conditions to the corresponding product in 88% yield (Table 4, entry 9), while 4-hydroxybenzaldehyde (**1u**) was treated with malononitrile and 3-methyl-1-phenyl-1*H*-pyrazol-5(4*H*)-one under optimized conditions to give **6j** in 90% yield (Table 4, entry 10). The cata-

Table 4

SBPPSP-catalyzed synthesis of dihydropyrano[2,3-*c*]pyrazole derivatives.

Entry	Ar	Product	Time (min)	Isolated yield (%)
1	C ₆ H ₅ - (1a)	6a	20	92
2	4-ClC ₆ H ₄ - (1b)	6b	15	95,94,92,90,89 ^a
3	2,4-(Cl) ₂ C ₆ H ₃ - (1e)	6c	15	89
4	4-BrC ₆ H ₄ - (1g)	6d	18	95
5	4-FC ₆ H ₄ - (1h)	6e	18	90
6	3-O ₂ NC ₆ H ₄ - (1i)	6f	15	90
7	4-O ₂ NC ₆ H ₄ - (1j)	6g	15	88
8	3,4-(CH ₃ O) ₂ C ₆ H ₃ - (1q)	6h	25	90
9	2-C ₁₀ H ₇ - (1t)	6i	25	88
10	4-HO-C ₆ H ₄ - (1u)	6j	25	90

Reaction conditions: 3-methyl-1-phenyl-1*H*-pyrazol-5(4*H*)-one 1 mmol, malononitrile 1 mmol, aldehyde 1 mmol, SBPPSP 0.05 g, H₂O:ethanol (1:1) 3 mL, reflux.

^a Recovered SBPPSP was used as catalyst

lyst was recycled four times in the three-component condensation reaction of malononitrile, 4-chlorobenzaldehyde, and 3-methyl-1-phenyl-1*H*-pyrazol-5(4*H*)-one (Table 4, entry 2).

3.4. Synthesis of 2-amino-3-cyano-4-aryl-4*H*-benzo[*e*]chromenes

Several protocols for the synthesis of 2-amino-4*H*-benzo[*e*]chromenes using various catalysts such as basic alumina [57], aqueous K₂CO₃ under microwave irradiation [10], *N,N*-dimethylaminoethylbenzyltrimethylammonium chloride [58], nanosized MgO [59], Mg/Al hydrotalcite [60], and cetyltrimethylammonium bromide [61] have been reported previously. These catalysts are either expensive or not suitable for preparation of some compounds, while in some cases ultrasonic irradiation is needed to achieve high yields. Recent catalysts for the synthesis of 2-amino-4*H*-benzo[*e*]chromenes include H₁₄[NaP₅W₃₀O₁₁₀] [62], basic ionic liquid [63], ceric ammonium nitrate [64], 1,8-diazabicyclo[5.4.0]undec-7-ene [65], ferric hydrogen sulfate and Zr-based catalysts [66], CeO₂-CaO nanocomposite oxide [73], and 1,4-Diazabicyclo[2.2.2]octane [74].

The synthesis of 2-amino-3-cyano-4-aryl-4*H*-benzo[*e*]chromenes was investigated by a one-pot, three-component condensation reaction between 1-naphthol, aromatic aldehyde, and malononitrile in the presence of SBPPSP in refluxing aqueous ethanol. As shown in Table 5, aromatic aldehydes substituted with electron-withdrawing groups such as 3-nitro or 4-nitro groups reacted under optimized conditions to give the corresponding products **7e** and **7f** in high yield.

Benzaldehydes functionalized with electron-donating groups such as 4-methyl (**1o**) or 3,4,5-trimethoxy (**1r**) groups also reacted well under optimized conditions to give the corresponding products in high yield (Table 5, entries 7 and 8). 4-Hydroxybenzaldehyde (**1u**) gave the corresponding product **7i** in 90% yield (Table 5, entry 9). In comparing substituent effects, we found that benzaldehydes substituted with electron-withdrawing groups such as nitro groups or halogens

Table 5

SBPPSP-catalyzed synthesis of 2-amino-3-cyano-4-aryl-4*H*-benzo[*e*]chromene derivatives.

Entry	Ar	Product	Time (min)	Isolated yield (%)
1	C ₆ H ₅ - (1a)	7a	30	91
2	4-ClC ₆ H ₄ - (1b)	7b	30	94,94,92,90,89 ^a
3	2-Cl-C ₆ H ₄ - (1d)	7c	35	84
4	4-BrC ₆ H ₄ - (1g)	7d	33	93
5	3-O ₂ NC ₆ H ₄ - (1i)	7e	45	93
6	4-O ₂ NC ₆ H ₄ - (1j)	7f	40	90
7	4-Me-C ₆ H ₄ - (1o)	7g	150	93
8	3,4,5-(CH ₃ O) ₃ C ₆ H ₂ - (1r)	7h	150	80
9	4-HO-C ₆ H ₄ - (1u)	7i	55	90

Reaction conditions: α-naphthol 1 mmol, malononitrile 1 mmol, aldehyde 1 mmol, SBPPSP 0.05 g, H₂O:ethanol (1:1) 3 mL, reflux.

^a Recovered SBPPSP was used as catalyst.

Scheme 2. Proposed mechanism for synthesis of pyran derivatives.

reacted with 1-naphthol and malononitrile faster than those substituted with electron-donating groups such as methyl or methoxy groups (Table 5). The catalyst was also recycled four times in the three-component condensation reaction of malononitrile, 4-chlorobenzaldehyde, and 1-naphthol (Table 5, entry 2).

According to our previous report [26] and Khurana et al. [65], a plausible mechanism for the reaction in the presence of a base is shown in Scheme 2. The α -cyanocinnamionitrile formed initially by Knoevenagel condensation in the presence of immobilized base undergoes subsequent reactions with α -carbonyl compound in the presence of the base to give the desired product.

4. Conclusions

Silica-bonded *N*-propylpiperazine sodium *n*-propionate (SBPPSP) was prepared from commercially available and inexpensive starting materials and efficiently catalyzed the synthesis of 3,4-dihydropyrano[c]chromenes, 2-amino-4*H*-pyrans, 1,4-dihydropyrano[2,3-*c*]-pyrazoles, and 2-amino-4*H*-benzo[e]-chromenes. The mild reaction conditions, simplicity of the procedure, and the ability to reuse the catalyst are particular advantages of this method.

Acknowledgments

We are thankful to Persian Gulf University Research Council for partial support of this work. Also, we are thankful to the School of Chemistry, Manchester University for running CHN, TGA, and SEM.

References

- [1] Zhu J, Bienayme H. Multicomponent Reactions. Weinheim: Wiley-VCH, 2005
- [2] Witte E C, Neubert P, Roesch A. DE 3427985. 1986
- [3] Hafez E A A, Elnagdi M H, Elagamey A G A, El-Taweel F M A A. *Heterocycles*, 1987, 26: 903
- [4] Kuthan J. *Adv Heterocycl Chem*, 1983, 34: 145
- [5] Hatakeyama S, Ochi N, Numata H, Takano S. *J Chem Soc, Chem Commun*, 1988: 1202
- [6] Zamocka J, Misikova E, Durinda J. *Pharmazie*, 1991, 46: 610
- [7] Wang J L, Liu D X, Zhang Z J, Shan S M, Han X B, Srinivasula S M, Croce C M, Alnemri E S, Huang Z W. *Proc Natl Acad Sci USA*, 2000, 97: 7124
- [8] El-Saghier A M M, Naili M B, Rammash B Kh, Saleh N A, Kredan K M. *Arkivoc*, 2007, (xvi): 83
- [9] Kumar R R, Perumal S, Senthilkumar P, Yogeeswari P, Sriram D. *Bioorg Med Chem Lett*, 2007, 17: 6459
- [10] Kidwai M, Saxena S, Khan M K R, Thukral S S. *Bioorg Med Chem Lett*, 2005, 15: 4295
- [11] Suarez M, Salfran E, Verdecia Y, Ochoa E, Alba L, Martin N, Martinez R, Quinteiro M, Seoane C, Novoa H, Blaton N, Peeters O M, De Ranter C. *Tetrahedron*, 2002, 58: 953
- [12] Kelly G J, King F, Kett M. *Green Chem*, 2002, 4: 392
- [13] Ertl G, Knözinger H, Weitkamp J. *Handbook of Heterogeneous Catalysis*. Weinheim: VCH, 1997
- [14] Dörwald F Z. *Organic Synthesis on Solid Phase: Supports, Linkers, Reactions*. Weinheim: John Wiley, 2002
- [15] Toy P H, Lam Y. *Solid-Phase Organic Synthesis: Concepts, Strategies, and Applications*. Hoboken: John Wiley, 2012
- [16] Sheldon R A, van Bekkum H. *Fine Chemicals through Heterogeneous Catalysis*. New York: Wiley-VCH Verlag GmbH, 2001. Chapter 7
- [17] Sheldon R A, Arends I, van Rantwijk F. *Green Chemistry and Catalysis*. Weinheim: John Wiley, 2006
- [18] Bartók M. *Chem Rev*, 2010, 110: 1663
- [19] Ding K, Uozumi Y. *Handbook of Asymmetric Heterogeneous Catalysis*. Weinheim: Wiley-VCH, 2008
- [20] Yokoi T, Kubota Y, Tatsumi T. *Appl Catal A*, 2012, 421-422: 14
- [21] Tang Y, Chen G, Lu Y. *Res Chem Intermediat*, 2012, 38: 937
- [22] Szöllösi G, Bartók M. *J Mol Struct*, 1999, 482-483: 13
- [23] Szöllösi G, Bartók M. *Catal Lett*, 1999, 59: 179
- [24] Tsuchiya S, Morishige H, Imamura H. *J Catal*, 1991, 129: 300
- [25] Weitkamp J, Hunger M, Ryma U. *Microporous Mesoporous Mater*, 2001, 48: 255
- [26] Niknam K, Jamali A. *Chin J Catal* (催化学报), 2012, 33: 1840
- [27] Niknam K, Habibabad M S, Deris A, Panahi F, Hormozi Nezhad M R. *J Iran Chem Soc*, 2013, 10: 527
- [28] Niknam K, Deris A, Panahi F. *Chin J Catal* (催化学报), 2013, 34: 718
- [29] Niknam K, Deris A, Panahi F, Hormozi Nezhad M R. *J Iran Chem Soc*, 2013, 10: 1291
- [30] Niknam K, Deris A, Naeimi F, Majleci F. *Tetrahedron Lett*, 2011, 52: 4642
- [31] Singh K, Singh J, Singh H. *Tetrahedron*, 1996, 52: 14273

Graphical Abstract

Chin. J. Catal., 2013, 34: 2245–2254 doi: 10.1016/S1872-2067(12)60693-7

Silica-bonded *N*-propylpiperazine sodium *n*-propionate as recyclable catalyst for synthesis of 4*H*-pyran derivatives

Khodabakhsh Niknam*, Nassim Borazjani, Reza Rashidian, Abbas Jamali
Persian Gulf University, Iran

Silica-bonded *N*-propylpiperazine sodium *n*-propionate is employed as a heterogeneous catalyst for the synthesis of pyran derivatives in refluxing aqueous ethanol.

- [32] Wang L M, Shao J H, Tian H, Wang Y H, Liu B. *J Fluorine Chem*, 2006, 127: 97
- [33] Balalaie S, Bararjanian M, Amani A M, Movassagh B. *Synlett*, 2006: 263
- [34] Peng Y Q, Song G H. *Catal Commun*, 2007, 8: 111
- [35] Gao S, Tsai C H, Tseng C, Yao C F. *Tetrahedron*, 2008, 64: 9143
- [36] Hasaninejad A, Shekouhy M, Golzar N, Zare A, Doroodmand M M. *Appl Catal A*, 2011, 402: 11
- [37] Sarrafi Y, Mehrasbi E, Vahid A, Tajbakhsh M. *Chin J Catal* (催化学报), 2012, 33: 1486
- [38] Martin N, Pascual C, Seoane C, Soto J L. *Heterocycles*, 1987, 26: 2811
- [39] Harb A F A, Hesien A H M, Metwally S A, Elnagdi M H. *Liebigs Ann Chem*, 1989: 585
- [40] Zayed S E, Abou Elmagd E I, Metwally S A, Elnagdi M H. *Collect Czech Chem Commun*, 1991, 56: 2175
- [41] Elnagdi M H, Abdel-Motaleb R M, Mustafa M, Zayed M F, Kamel E M. *J Heterocycl Chem*, 1987, 24: 1677
- [42] Babu N S, Pasha N, Rao K T V, Prasad P S S, Lingaiah N. *Tetrahedron Lett*, 2008, 49: 2730
- [43] Kumar D, Reddy V B, Sharad S, Dube U, Kapur S. *Eur J Med Chem*, 2009, 44: 3805
- [44] Banerjee S, Horn A, Khatri H, Sereda G. *Tetrahedron Lett*, 2011, 52: 1878
- [45] Pratap U R, Jawale D V, Netankar P D, Mane R A. *Tetrahedron Lett*, 2011, 52: 5817
- [46] Thumar N J, Patel M P. *Arkivoc*, 2009, (xiii): 363
- [47] Shi D Q, Mou J, Zhuang Q Y, Niu L H, Wu N, Wang X S. *Synth Commun*, 2004, 34: 4557
- [48] Jin T S, Wang A Q, Cheng Z L, Zhang J S, Li T S. *Synth Commun*, 2005, 35: 137
- [49] Guo S B, Wang S X, Li J T. *Synth Commun*, 2007, 37: 2111
- [50] Lehmann F, Holm M, Laufer S. *J Comb Chem*, 2008, 10: 364
- [51] Al-Matar H M, Khalil K D, Adam A Y, Elnagdi M H. *Molecules*, 2010, 15: 6619
- [52] Heravi M M, Ghods A, Derikvand F, Bakhiari K, Bamoharram F F. *J Iran Chem Soc*, 2010, 7: 615
- [53] Siddekha A, Nizam A, Pasha M A. *Spectrochim Acta A*, 2011, 81: 431
- [54] Mandha S R, Siliveri S, Alla M, Bommena V R, Bommineni M R, Balasubramanian S. *Bioorg Med Chem Lett*, 2012, 22: 5272
- [55] Azzam S H S, Pasha M A. *Tetrahedron Lett*, 2012, 53: 6834
- [56] Niknam K, Piran A. *Green Sustain Chem*, 2013, 3(2A): 1
- [57] Maggi R, Ballini R, Sartori G, Sartorio R. *Tetrahedron Lett*, 2004, 45: 2297
- [58] Zhou D, Ren Z J, Cao W G, Chen J, Deng H M. *J Heterocyclic Chem*, 2008, 45: 1865
- [59] Kumar D, Reddy V B, Mishra B G, Rana R K, Nadagouda M N, Varma R S. *Tetrahedron*, 2007, 63: 3093
- [60] Surpur M P, Kshirsagar S, Samant S D. *Tetrahedron Lett*, 2009, 50: 719
- [61] Jin T S, Xiao J C, Wang S J, Li T S. *Ultrason Sonochem*, 2004, 11: 393
- [62] Heravi M M, Bakhtiari K, Zadsirjan V, Bamoharram F F, Heravi O M. *Bioorg Med Chem Lett*, 2007, 17: 4262
- [63] Gong K, Wang H L, Fang D, Liu Z L. *Catal Commun*, 2008, 9: 650
- [64] Kumar A, Sharma S, Maurya R A, Sarkar J. *J Comb Chem*, 2010, 12: 20
- [65] Khurana J M, Nand B, Saluja P. *Tetrahedron*, 2010, 66: 5637
- [66] Eshghi H, Damavandi S, Zohuri G H. *Syn Reac Inorg Metal-Org Nano Metal Chem*, 2011, 41: 1067
- [67] Hassanien A A, Zahran M A, El-Gaby M S A, Ghorab M M. *J Indian Chem Soc*, 1999, 76: 350
- [68] Zhou J F, Tu S J, Gao Y, Ji M. *Chin J Org Chem*, 2001, 21: 742
- [69] Tu S J, Jiang H, Zhuang Q Y, Miao C B, Shi D Q, Wang X S, Gao Y. *Chin J Org Chem*, 2003, 23: 488
- [70] Jin T S, Wang A Q, Wang X, Zhang J S, Li T S. *Synlett*, 2004: 871
- [71] Shi D Q, Zhang S, Zhuang Q Y, Tu S J, Hu H W. *Chin J Org Chem*, 2003, 23: 877
- [72] Wang X S, Shi D Q, Tu S J, Yao C S. *Synth Commun*, 2003, 33: 119
- [73] Samantaray S, Pradhan D K, Hota G, Mishra B G. *Chem Eng J*, 2012, 193-194: 1
- [74] Shinde S, Rashinkar G, Salunkhe R. *J Mol Liq*, 2013, 178: 122