Silica-Bonded *N*-Propylpiperazine Sodium *n*-Propionate as Recyclable Basic Catalyst for Synthesis of 3,4-Dihydropyrano[*c*]chromene Derivatives and Biscoumarins

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Abstract: A simple and efficient procedure for the preparation of silica-bonded *N*-propylpiperazine sodium *n*-propionate (SBPPSP) by the hydrolysis of silica-bonded *N*-propylpiperazine methyl *n*-propionate (SBPPMP) in hydrochloric acid (0.5 mol/L) followed by treatment with saturated sodium bicarbonate is described. The SBPPMP was obtained by the reaction of 3-silica-bonded *N*-propylpiperazine and methyl acrylate in methanol. SBPPSP was used as a recyclable basic catalyst for the synthesis of 3,4-dihydropyrano[*c*]chromenes by the reaction of aromatic aldehydes, malononitrile, and 4-hydroxycoumarin in aqueous ethanol (1:1 v/v) under reflux conditions. Biscoumarins were also obtained via condensation of aldehydes and 4-hydroxycoumarin in aqueous ethanol (1:1 v/v) under reflux conditions. The catalyst could be recycled several times without any additional treatment.

Key words: silica-bonded *N*-propylpiperazine sodium *n*-propionate; silica-bonded *N*-propylpiperazine methyl *n*-propionate; aromatic aldehydes; 3,4-dihydropyrano[*c*]chromenes; biscoumarins

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Multi-component reactions have received considerable attention because they are powerful synthetic tools for the synthesis of biologically active compounds [1]. In terms of green chemistry, the development and application of multi-component coupling reactions in aqueous media is desirable, as they provide simple and rapid access to a large number of organic molecules through a sustainable path [2]. The elimination of solvents in chemical processes or the replacement of hazardous solvents with relatively benign, clean, cheap, non-flammable, and naturally occurring solvents with high specific heat capacities are primary objectives.

Base-catalyzed reactions such as aldol and Knoevenagel condensations and Michael additions are important industrially in the production of drugs, fragrances, and chemical intermediates [3–5]. Conventionally, nearly stoichiometric amounts of homogeneous bases are used for such purposes [3,6,7]. These systems have a number of disadvantages such as tedious isolation of products, the corrosive nature of the reaction mixtures, and the formation of large amounts of waste materials. Improved synthetic methods in terms of product purity, yield, and minimum waste formation are therefore highly desirable. Moreover, the replacement of liquid acids and bases with the corresponding cleaner solid alternatives with desirable characteristics such as being

non-stoichiometric, non-corrosive, and reusable is also attractive. The use of solid basic catalysts such as hydrotalcites and basic zeolites has been studied in numerous reactions [8,9]. The potential use of microporous and mesoporous basic catalysts in fine-chemical production is enormous [4], particularly because such catalysts are known to suppress side reactions. Their use also avoids complex neutralization and separation steps, and the recovered catalysts can be readily regenerated for further use.

Dihydropyrano[*c*]chromenes and their derivatives are of considerable interest as they possess a wide range of biological properties [10] such as spasmolytic, diuretic, anti-coagulant, anticancer, and anti-anaphylactic activities [11,12]. In addition, they can be used as cognitive enhancers for the treatment of neurodegenerative diseases, including Alzheimer's disease, Parkinson's disease, AIDS-associated dementia, and Down's syndrome, as well as for the treatment of schizophrenia and myoclonus [13]. Also, a number of 2-amino-4*H*-pyranes are useful as photoactive materials [14]. A number of methods have been reported for the synthesis of 3,4-dihydropyrano[*c*]chromenes, e.g., using piperidine in organic solvents, ethanol and pyridine [15], K₂CO₃ under microwave irradiation [16], diammonium hydrogen phosphate [17], tetrabutylammonium bromide [18], nanostructured ZnO [1], DBU [19], and morpholine

[20].

Here we report the synthesis of 3,4-dihydropyrano[c]chromenes and biscoumarins in the presence of SBPPSP as a heterogeneous and recyclable solid basic catalyst.

1 Experimental

1.1 General

Chemicals were purchased from Fluka, Merck, and Aldrich Chemical Companies. All the products were characterized by comparison of their infrared (IR), ^1H nuclear magnetic resonance (NMR), and ^{13}C NMR spectra, and their melting points with the reported data [15–25]. 3-Piperazine-*N*-propylsilica (3-PNPS) was prepared according to a previously reported procedure [26].

1.2 Catalyst preparation

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

To a magnetically stirred mixture of 3-PNPS (25 g) in MeOH (50 ml), methyl acrylate (25 ml) was added and the mixture was heated at 40–50 °C for 48 h under nitrogen. The mixture was then 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 gave the following results: C, H, and N, 13.47%, 2.28%, and 2.18%, respectively.

1.2.2 Preparation of silica-bonded *N*-propylpiperazine sodium *N*-propionate (SBPPSP)

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

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

1.3 General procedure for synthesis of 3,4-dihydropyrano[c]chromenes

To a mixture of 4-hydroxycoumarin (1 mmol) and an aromatic aldehyde (1 mmol) in aqueous ethanol (5 ml, 1:1

v/v) the SBPPSP catalyst (0.06 g, 5.2 mol%) was added and the mixture was refluxed. After completion of the reaction, as indicated by thin-layer chromatography, the reaction mixture was filtered. The residue was washed with warm ethanol (3 × 30 ml) to separate the heterogeneous catalyst. After cooling, the crude products were precipitated. The crude products were purified by recrystallization from ethanol (95%). The recovered catalyst was dried and reused for subsequent runs.

2-Amino-4-phenyl-4,5-dihydro-5-oxopyrano[3,2-*c*]chromene-3-carbonitrile (**1a**). ^1H NMR (400 MHz, DMSO-d_6): δ 4.46 (s, 1H), 7.23–7.27 (m, 3H), 7.31–7.35 (m, 2H), 7.43–7.52 (m, 2H), 7.72 (dt, 1H, $J_1 = 7.8$ Hz, $J_2 = 1.6$ Hz), 7.92 (dd, 1H, $J_1 = 8.0$ Hz, $J_2 = 0.8$ Hz). ^{13}C NMR (100 MHz, DMSO-d_6): δ 58.41, 104.47, 113.42, 117.06, 119.68, 122.98, 125.18, 127.62, 128.10, 129.01, 133.45, 143.80, 152.60, 153.89, 158.36, 158.40, 160.05.

2-Amino-4-(4-chlorophenyl)-4,5-dihydro-5-oxopyrano[3,2-*c*]chromene-3-carbonitrile (**1b**). ^1H NMR (400 MHz, DMSO-d_6): δ 4.49 (s, 1H), 7.31 (d, 2H, $J = 8.4$ Hz), 7.38 (d, 2H, $J = 8.4$ Hz), 7.45–7.51 (m, 2H), 7.72 (t, 1H, $J = 7.8$ Hz), 7.91 (d, 1H, $J = 8.0$ Hz). ^{13}C NMR (100 MHz, DMSO-d_6): δ 57.94, 103.94, 113.39, 117.06, 119.54, 123.01, 125.18, 128.92, 130.12, 132.18, 133.51, 142.80, 152.64, 154.02, 158.34, 158.38, 160.03.

2-Amino-4-(3-chlorophenyl)-4,5-dihydro-5-oxopyrano[3,2-*c*]chromene-3-carbonitrile (**1c**). ^1H NMR (400 MHz, DMSO-d_6): δ 4.52 (s, 1H), 7.26 (d, 1H, $J = 7.2$ Hz), 7.31–7.38 (m, 3H), 7.47–7.53 (m, 2H), 7.73 (t, 1H, $J = 7.6$ Hz), 7.91 (d, 1H, $J = 7.6$ Hz). ^{13}C NMR (100 MHz, DMSO-d_6): δ 57.81, 103.63, 113.43, 117.02, 119.55, 123.06, 125.13, 127.03, 127.66, 128.06, 130.87, 133.48, 133.54, 146.26, 152.66, 154.19, 158.37, 158.42, 160.06.

2-Amino-4-(4-bromophenyl)-4,5-dihydro-5-oxopyrano[3,2-*c*]chromene-3-carbonitrile (**1d**). ^1H NMR (400 MHz, DMSO-d_6): δ 4.48 (s, 1H), 7.25 (d, 2H, $J = 8.0$ Hz), 7.46–7.52 (m, 4H), 7.73 (t, 1H, $J = 7.4$ Hz), 7.91 (d, 1H, $J = 7.6$ Hz). ^{13}C NMR (100 MHz, DMSO-d_6): δ 57.85, 103.88, 113.39, 117.08, 119.54, 120.71, 123.02, 125.20, 130.50, 131.85, 133.54, 143.23, 152.65, 154.03, 158.32, 160.04.

2-Amino-4-(3-nitrophenyl)-4,5-dihydro-5-oxopyrano[3,2-*c*]chromene-3-carbonitrile (**1e**). ^1H NMR (400 MHz, DMSO-d_6): δ 4.74 (s, 1H), 7.46–7.53 (m, 2H), 7.58 (s, 2H, NH_2), 7.64 (t, 1H, $J = 8.0$ Hz), 7.74 (dt, 1H, $J_1 = 7.9$ Hz, $J_2 = 1.4$ Hz), 7.82 (d, 1H, $J = 7.6$ Hz), 7.93 (dd, 1H, $J_1 = 8.0$ Hz, $J_2 = 1.2$ Hz), 8.12–8.15 (m, 2H). ^{13}C NMR (100 MHz, DMSO-d_6): δ 57.36, 103.33, 113.39, 117.07, 119.45, 122.77, 122.93, 123.10, 125.19, 130.56, 133.61, 135.26, 145.96, 148.30, 152.73, 154.35, 158.52, 158.57, 160.10.

2-Amino-4-(4-nitrophenyl)-4,5-dihydro-5-oxopyrano[3,2-*c*]chromene-3-carbonitrile (**1f**). ^1H NMR (400 MHz, DMSO-d_6): δ 4.68 (s, 1H), 7.47–7.54 (m, 2H), 7.58–7.61

(m, 2H), 7.75 (dt, 1H, $J_1 = 8.0$ Hz, $J_2 = 1.2$ Hz), 7.93 (dd, 1H, $J_1 = 8.0$ Hz, $J_2 = 1.2$ Hz), 8.21 (d, 2H, $J = 8.4$ Hz). ^{13}C NMR (100 MHz, DMSO- d_6): δ 57.20, 103.27, 113.36, 117.13, 119.34, 123.09, 124.22, 125.26, 129.67, 133.69, 147.08, 151.23, 152.74, 154.42, 158.43, 158.47, 160.07.

2-Amino-4-(2-nitrophenyl)-4,5-dihydro-5-oxopyrano[3,2-*c*]chromene-3-carbonitrile (**1g**). ^1H NMR (400 MHz, DMSO- d_6): δ 5.25 (s, 1H), 7.46–7.59 (m, 6H), 7.67 (t, 1H, $J = 7.6$ Hz), 7.73 (t, 1H, $J = 7.8$ Hz), 7.91 (d, 2H, $J = 7.6$ Hz). ^{13}C NMR (100 MHz, DMSO- d_6): δ 56.52, 103.75, 113.27, 117.09, 119.22, 123.03, 124.45, 125.21, 128.93, 131.65, 133.57, 134.16, 137.83, 149.66, 152.63, 154.06, 159.08, 160.19. Elemental analysis for $\text{C}_{19}\text{H}_{11}\text{N}_3\text{O}_5$: C, 63.16; H, 3.07; N, 11.63. Found: C, 62.96; H, 3.12; N, 11.41.

2-Amino-4-*p*-tolyl-4,5-dihydro-5-oxopyrano[3,2-*c*]chromene-3-carbonitrile (**1h**). ^1H NMR (400 MHz, DMSO- d_6): δ 2.27 (s, 3H), 4.41 (s, 1H), 7.11–7.15 (m, 4H), 7.40 (s, 2H, NH_2), 7.46–7.52 (m, 2H), 7.72 (dt, 1H, $J_1 = 7.8$ Hz, $J_2 = 1.6$ Hz), 7.91 (dd, 1H, $J_1 = 7.8$ Hz, $J_2 = 1.4$ Hz). ^{13}C NMR (100 MHz, DMSO- d_6): δ 21.10, 58.53, 104.59, 113.42, 117.03, 119.71, 122.94, 125.15, 128.00, 129.55, 133.38, 136.78, 140.86, 152.56, 153.72, 158.30, 160.01.

2-Amino-4-(3,4,5-trimethoxy-phenyl)-4,5-dihydro-5-oxopyrano[3,2-*c*]chromene-3-carbonitrile (**1i**). ^1H NMR (400 MHz, DMSO- d_6): δ 3.64 (s, 3H), 3.72 (s, 6H), 4.44 (s, 1H), 6.53 (s, 2H), 7.41 (s, 2H, NH_2), 7.47–7.52 (m, 2H), 7.73 (dt, 1H, $J_1 = 8.0$ Hz, $J_2 = 1.6$ Hz), 7.91 (dd, 1H, $J_1 = 8.0$ Hz, $J_2 = 1.6$ Hz). ^{13}C NMR (100 MHz, DMSO- d_6): δ 56.36, 58.32, 60.39, 104.11, 105.38, 113.54, 117.05, 119.71, 123.04, 125.11, 133.39, 137.03, 139.46, 152.64, 153.30, 153.98, 158.38, 160.14. Elemental analysis for $\text{C}_{22}\text{H}_{18}\text{N}_2\text{O}_6$: C, 65.02; H, 4.46; N, 6.89. Found: C, 64.81; H, 4.52; N, 6.63.

2-Amino-4-(4-hydroxy-phenyl)-4,5-dihydro-5-oxopyrano[3,2-*c*]chromene-3-carbonitrile (**1j**). ^1H NMR (400 MHz, DMSO- d_6): δ 4.33 (s, 1H), 6.71 (d, 2H, $J = 8.4$ Hz), 7.06 (d, 0.72H, $J = 8.8$ Hz), 7.36 (s, 2H, NH_2), 7.43–7.49 (m, 2H), 7.69 (dt, 1H, $J_1 = 7.8$ Hz, $J_2 = 1.6$ Hz), 7.89 (dd, 1H, $J_1 = 7.8$ Hz, $J_2 = 1.4$ Hz), 9.41 (s, 1H, OH). ^{13}C NMR (100 MHz, DMSO- d_6): δ 58.84, 104.92, 113.43, 115.59, 116.96, 119.87, 122.89, 125.09, 129.20, 133.25, 134.23, 152.48, 153.42, 156.80, 158.32, 160.02.

2-Amino-4-(3-hydroxy-phenyl)-4,5-dihydro-5-oxopyrano[3,2-*c*]chromene-3-carbonitrile (**1k**). ^1H NMR (400 MHz, DMSO- d_6): δ 4.35 (s, 1H), 6.63–6.69 (m, 3H), 7.11 (t, 1H, $J = 8.2$ Hz), 7.42 (s, 2H, NH_2), 7.46–7.52 (m, 2H), 7.72 (dt, 1H, $J_1 = 7.8$ Hz, $J_2 = 1.2$ Hz), 7.91 (d, 1H, $J = 7.2$ Hz), 9.42 (s, 1H, OH). ^{13}C NMR (100 MHz, DMSO- d_6): δ 58.47, 104.59, 113.35, 114.58, 114.67, 117.04, 118.73, 119.75, 122.88, 125.18, 130.03, 133.42, 145.21, 152.54, 153.77, 157.77, 158.38, 158.43, 160.01.

1.4 General procedure for the synthesis of

biscoumarins

To a mixture of 4-hydroxycoumarin (2 mmol) and aromatic aldehyde (1 mmol) in aqueous ethanol (5 ml, 1:1 v/v) catalyst SBPPSP (0.06 g, 5.2 mol%) was added and the mixture was refluxed. After completion of the reaction, as indicated by TLC, the reaction mixture was filtered. The remaining was washed with warm ethanol (3 $\times$ 30 ml) in order to separate heterogeneous catalyst. After cooling the crude products were precipitated. The crude products were purified by recrystallization from ethanol (95%). The recovered catalyst was dried and reused for subsequent runs.

3,3'-(phenylmethylene)-bis-(4-hydroxycoumarin) (**4a**). ^1H NMR (400 MHz, CDCl_3): δ 6.13 (s, 1H), 7.24–7.50 (m, 9H), 7.64–7.68 (m, 2H), 8.02–8.14 (m, 2H), 11.35 (s, 1H, OH), 11.57 (s, 1H, OH). ^{13}C NMR (100 MHz, CDCl_3): δ 36.20, 103.90, 105.65, 116.46, 124.42, 124.92, 126.50, 126.90, 128.66, 132.90, 135.21, 152.32, 152.55, 164.62, 165.82, 166.89.

3,3'-(4-chlorophenylmethylene)-bis-(4-hydroxycoumarin) (**4b**). ^1H NMR (400 MHz, CDCl_3): δ 6.07 (s, 1H), 7.18 (d, 2H, $J = 8.4$ Hz), 7.31 (d, 2H, $J = 8.8$ Hz), 7.39–7.45 (m, 4H), 7.64–7.69 (m, 2H), 8.02 (d, 1H, $J = 8.0$ Hz), 8.10 (d, 1H, $J = 7.8$ Hz), 11.35 (s, 1H, OH), 11.57 (s, 1H, OH). ^{13}C NMR (100 MHz, CDCl_3): δ 35.83, 103.71, 105.27, 116.36, 132.74, 133.07, 133.87, 152.30, 152.55, 164.67, 166.04, 166.87, 169.23.

3,3'-(4-bromophenylmethylene)-bis-(4-hydroxycoumarin) (**4c**). ^1H NMR (400 MHz, CDCl_3): δ 6.04 (s, 1H), 7.12 (d, 2H, $J = 8.4$ Hz), 7.39–7.47 (m, 6H), 7.65–7.69 (m, 2H), 8.01–8.10 (m, 2H), 11.35 (s, 1H, OH), 11.56 (s, 1H, OH). ^{13}C NMR (100 MHz, CDCl_3): δ 35.91, 103.65, 105.21, 116.37, 116.71, 116.84, 120.82, 124.44, 125.02, 128.37, 131.73, 133.07, 134.47, 152.30, 152.56, 164.65, 166.05, 166.86, 169.21.

3,3'-(4-fluorophenylmethylene)-bis-(4-hydroxycoumarin) (**4d**). ^1H NMR (400 MHz, CDCl_3): δ 6.07 (s, 1H), 7.03 (t, 2H, $J = 8.4$ Hz), 7.19–7.23 (m, 2H), 7.42–7.44 (m, 4H), 7.64–7.68 (m, 2H), 8.01–8.10 (m, 2H), 11.35 (s, 1H, OH), 11.57 (s, 1H, OH). ^{13}C NMR (100 MHz, CDCl_3): δ 35.68, 103.95, 105.49, 115.41, 115.63, 116.39, 116.68, 116.87, 124.41, 124.98, 128.14, 128.22, 130.84, 130.87, 133.01, 152.29, 152.54, 161.72 (d, $J_{\text{C-F}} = 244.0$ Hz), 164.63, 165.93, 166.86, 169.23.

3,3'-(3-nitrophenylmethylene)-bis-(4-hydroxycoumarin) (**4e**). ^1H NMR (400 MHz, CDCl_3): δ 6.15 (s, 1H), 7.41–7.48 (m, 4H), 7.54 (t, 1H, $J = 7.8$ Hz), 7.61 (d, 1H, $J = 7.6$ Hz), 7.70 (t, 2H, $J = 7.8$ Hz), 8.02 (d, 1H, $J = 8.0$ Hz), 8.10–8.13 (m, 2H), 8.17 (d, 1H, $J = 8.0$ Hz), 11.41 (s, 1H, OH), 11.60 (s, 1H, OH). ^{13}C NMR (100 MHz, CDCl_3): δ 36.20, 103.24, 104.64, 116.29, 116.76, 116.87, 121.79, 122.16, 124.53, 125.17, 125.23, 129.61, 132.81, 133.37, 137.99, 148.76,

152.37, 152.63, 164.88, 166.61, 167.00, 169.16.

3,3'-(4-nitrophenylmethylene)-bis-(4-hydroxycoumarin) (**4f**). ^1H NMR (400 MHz, CDCl_3): δ 6.12 (s, 1H), 7.41–7.46 (m, 6H), 7.68 (t, 2H, $J = 7.6$ Hz), 8.01 (d, 1H, $J = 7.6$ Hz), 8.10 (d, 1H, $J = 7.6$ Hz), 8.20 (d, 2H, $J = 8.4$ Hz), 11.39 (s, 1H, OH), 11.58 (s, 1H, OH). ^{13}C NMR (100 MHz, CDCl_3): δ 36.53, 103.28, 104.77, 116.23, 116.67, 116.75, 116.82, 123.89, 124.47, 124.52, 125.17, 125.24, 127.59, 133.39, 143.38, 146.87, 152.32, 152.57, 164.84, 166.44, 167.01, 169.11.

3,3'-(4-cyanophenylmethylene)-bis-(4-hydroxycoumarin) (**4g**). IR (KBr): 3050, 2990, 2980, 2700, 2600, 2200, 1690, 1680, 1610, 1590, 1565, 1510, 1480, 1380, 1220, 1180, 1095, 960, 905, 880, 790, 775 cm^{-1} . ^1H NMR (400 MHz, CDCl_3): δ 6.12 (s, 1H), 7.37–7.47 (m, 6H), 7.64–7.71 (m, 4H), 8.02 (d, 1H, $J = 7.6$ Hz), 8.11 (d, 1H, $J = 8.0$ Hz), 11.38 (s, 1H, OH), 11.57 (s, 1H, OH). ^{13}C NMR (100 MHz, CDCl_3): δ 36.56, 103.15, 104.23, 110.92, 116.26, 116.74, 118.69, 124.48, 125.15, 125.21, 127.46, 132.49, 133.34, 141.28, 152.33, 152.58, 164.81, 166.45, 166.98, 169.16. Elemental analysis for $\text{C}_{26}\text{H}_{15}\text{NO}_6$: C, 71.39; H, 3.46; N, 3.20. Found: C, 71.20; H, 3.52; N, 3.02.

3,3'-(*p*-tolylmethylene)-bis-(4-hydroxycoumarin) (**4h**). ^1H NMR (400 MHz, CDCl_3): δ 2.36 (s, 3H), 6.09 (s, 1H), 7.11–7.17 (m, 4H), 7.44 (d, 4H, $J = 8.4$ Hz), 7.63–7.67 (m, 2H), 8.02–8.09 (m, 2H), 11.33 (s, 1H, OH), 11.55 (s, 1H, OH). ^{13}C NMR (100 MHz, CDCl_3): δ 21.04, 35.89, 104.10, 105.75, 116.97, 124.40, 124.88, 129.36, 132.06, 132.82, 136.50, 152.30, 152.54, 164.65, 166.72, 166.87, 169.34.

3,3'-(4-methoxyphenylmethylene)-bis-(4-hydroxycoumarin) (**4i**). ^1H NMR (400 MHz, CDCl_3): δ 3.82 (s, 3H), 6.07 (s, 1H), 6.87 (d, 2H, $J = 8.4$ Hz), 7.14 (d, 2H, $J = 8.4$ Hz), 7.42–7.44 (m, 4H), 7.65 (t, 2H, $J = 7.6$ Hz), 8.03–8.08 (m,

2H), 11.33 (brs, 1H, OH), 11.54 (s, 1H, OH). ^{13}C NMR (100 MHz, CDCl_3): δ 35.53, 55.28, 104.22, 105.79, 114.02, 116.63, 116.97, 124.37, 124.88, 126.95, 127.63, 132.83, 152.28, 152.52, 158.43, 164.52, 165.66, 166.82, 169.26.

3,3'-(3,4,5-trimethoxyphenylmethylene)-bis-(4-hydroxycoumarin) (**4j**). IR (KBr): 3050, 2990, 2900, 2710, 2600, 1665, 1645, 1610, 1580, 1502, 1450, 1415, 1350, 1125, 805, 760 cm^{-1} . ^1H NMR (400 MHz, CDCl_3): δ 3.74 (s, 6H), 3.87 (s, 3H), 6.10 (s, 1H), 6.45 (s, 2H), 7.44 (d, 4H, $J = 8.4$ Hz), 7.64–7.68 (m, 2H), 8.05–8.08 (m, 2H), 11.31 (s, 1H, OH), 11.59 (s, 1H, OH). ^{13}C NMR (100 MHz, CDCl_3): δ 36.25, 56.36, 60.94, 104.27, 116.71, 124.34, 125.00, 130.91, 132.97, 137.20, 152.48, 153.38, 164.66, 165.71, 166.75, 169.18. Elemental analysis for $\text{C}_{28}\text{H}_{22}\text{O}_9$: C, 66.93; H, 4.41. Found: C, 66.74; H, 4.47.

3,3'-(4-hydroxyphenylmethylene)-bis-(4-hydroxycoumarin) (**4k**). IR (KBr): 3340, 3020, 2990, 2710, 2600, 1680, 1660, 1620, 1600, 1550, 1530, 1440, 1360, 1315, 1275, 1202, 1175, 1100, 1080, 960, 905, 830, 760 cm^{-1} . ^1H NMR (400 MHz, CDCl_3): δ 5.57 (brs, 1H, OH), 6.06 (s, 1H), 6.81 (d, 2H, $J = 8.4$ Hz), 7.09 (d, 2H, $J = 8.4$ Hz), 7.41–7.43 (m, 4H), 7.65 (t, 2H, $J = 8.4$ Hz), 8.03–8.07 (m, 2H), 11.32 (brs, 1H, OH), 11.50 (s, 1H, OH). ^{13}C NMR (100 MHz, CDCl_3): δ 35.47, 104.17, 105.70, 115.74, 116.66, 124.36, 124.97, 126.47, 127.73, 132.95, 152.38, 154.91, 164.68, 165.87, 167.09, 169.38. Elemental analysis for $\text{C}_{25}\text{H}_{16}\text{O}_7$: C, 70.09; H, 3.76. Found: C, 69.89; H, 3.81.

2 Results and Discussion

As a continuation of our studies on the design and application of silica-functionalized solid acids or bases as catalysts in organic transformations [27–34], we prepared

Scheme 1. Preparation of SBPPSP.

SBPPSP and studied its catalytic activity in the synthesis of pyrano[*c*]chromenes and biscoumarins. SBPPSP was prepared by the reaction of 3-silica-bonded *N*-propylpiperazine and methyl acrylate in methanol, followed by hydrolysis with HCl (0.5 mol/L) and treatment with saturated sodium bicarbonate (Scheme 1). Elemental analysis gave the following results: C, H, and N, 13.72%, 2.30%, and 2.78%, respectively.

The thermogravimetric analysis (TGA) curves of SBPPSP show mass loss of organic materials as they decompose upon heating (Fig. 1). The initial mass loss from the SBPPSP up to 130 °C is the result of the 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 per g of catalyst. Covalent chemical bonds give the catalyst high thermal stability, so it is possible that the catalyst could be used for high-temperature applications.

Figure 2 shows the Fourier-transform IR (FT-IR) spectrum of SBPPSP. The major peaks for silica (SiO₂) are broad antisymmetric Si–O–Si stretching from 1300 to 1000 cm^{−1} and symmetric Si–O–Si stretching at 820–780 cm^{−1}.

For carboxylate salt functional groups, the FT-IR absorption of the stretching mode is at 1650 cm^{−1}. The FT-IR spectrum shows an overlap of the asymmetric and symmetric stretching bands of O=C–O with the Si–O–Si stretching bands in the silica-functionalized alkyl carboxylate. In the FT-IR spectrum of 3-PNPS, the stretching mode of the carboxylate ester is at 1739.7 cm^{−1}, and it disappeared on conversion to a carboxylate salt (not shown).

To study the effect of catalyst loading on the synthesis of

Fig. 1. TGA of SBPPSP.

Fig. 2. FT-IR spectrum of SBPPSP.

2-amino-4-aryl-5-oxo-4*H*,5*H*-pyrano[3,2-*c*]chromene-3-carbonitrile, the condensation reaction of malononitrile, 4-chlorobenzaldehyde, and 4-hydroxycoumarin was chosen as a model reaction (Table 1). The results clearly show that SBPPSP is an effective catalyst for this condensation, and

Table 1 Effects of catalyst and solvent on the reaction of 4-chlorobenzaldehyde, malononitrile, and 4-hydroxycoumarin under reflux conditions

Entry	Catalyst	Catalyst loading (g)	Solvent	Time (min)	Isolated yield (%)
1	SBPPSP	0.06	EtOH	20	90
2	SBPPSP	0.06	H ₂ O	60	80
3	SBPPSP	0.06	H ₂ O/EtOH (1:1, v/v)	10	95
4	SBPPSP	0.06	H ₂ O/EtOH (2:1, v/v)	15	88
5	SBPPSP	0.03	H ₂ O/EtOH (1:1, v/v)	20	80
6	SBPPSP	0.01	H ₂ O/EtOH (1:1, v/v)	40	62
7	SBPPSP	0.09	H ₂ O/EtOH (1:1, v/v)	10	95
8	SBPPSP	0.06	solvent-free	60	51 ^a
9	SBPPSP	0.06	solvent-free	60	80 ^b
10	SBPPSP	0.08	solvent-free	60	80 ^a
11	SBPPSP	0.08	solvent-free	60	90 ^b
12	PNPS	0.06	H ₂ O/EtOH (1:1, v/v)	90	80
13	SBPM	0.06	H ₂ O	60	30
14	SBPM	0.06	H ₂ O/EtOH (1:1, v/v)	90	90
15	Et ₃ N	0.01	H ₂ O/EtOH (1:1, v/v)	30	68
16		0.008	H ₂ O/EtOH (1:1, v/v)	30	70

^aReaction was accomplished at 80 °C. ^bReaction was accomplished at 100 °C.

Scheme 2. SBPPSP-catalyzed synthesis of 2-amino-4-aryl-5-oxo-4*H*,5*H*-pyrano[3,2-*c*]chromene-3-carbonitrile derivatives.

the optimal amount of SBPPSP was 0.06 g (5.2 mol%) per mmol of aldehyde in refluxing aqueous ethanol (1:1 v/v). This condensation was carried out with lower amounts of SBPPSP, i.e., 0.01 and 0.03 g, and the corresponding products were obtained in 62% and 80% yield (Table 1, entries 5 and 6). This three-component condensation was also accomplished in the presence of SBPPSP in ethanol and water under reflux conditions for a longer reaction time (Table 1, entries 1 and 2). The model reaction was also examined under solvent-free conditions at 80 °C and gave **1b** in 51% yield after 60 min (Table 1, entry 8). When the amount of catalyst was increased to 0.08 g and the temperature to 100 °C, the yield of **1b** increased to 90% (Table 1, entries 9–11). The model reaction was performed in the presence of silica-bonded *N*-propylpiperazine (PNPS) [26] in aqueous ethanol under reflux conditions, giving 80% yield (Table 1, entry 12). In addition, the same model reaction was carried out in the presence of silica-bonded *N*-propylmorpholine (SBPM) [35] in water and aqueous ethanol (1:1, v/v) for 60 and 90 min, giving yields of 30% and 90%, respectively.

(Table 1, entries 13 and 14).

The synthesis of 2-amino-4-aryl-5-oxo-4*H*,5*H*-pyrano [3,2-*c*]chromene-3-carbonitrile was achieved by the three-component condensation of an aromatic aldehyde, malononitrile, and 4-hydroxycoumarin in the presence of SBPPSP (0.06 g, 5.2 mol%) in aqueous ethanol (1:1 v/v) under reflux conditions (Scheme 2).

A series of 3,4-dihydropyrano[*c*]chromene derivatives were prepared successfully from different aromatic aldehydes bearing electron-withdrawing and electron-donating groups, 4-hydroxycoumarin, and malononitrile in refluxing aqueous ethanol (1:1 v/v). Compounds bearing electron-withdrawing groups, i.e., 3-nitro-, 4-nitro-, and 2-nitro-benzaldehyde, reacted under the optimized conditions to give **1e**, **1f**, and **1g** in 94%, 95%, and 91% yields, respectively after 8–10 min (Table 2, entries 5–7). Compounds bearing electron-donating groups, i.e., 4-Me and 3,4,5-(MeO)₃-benzaldehyde, were treated with malononitrile and 4-hydroxycoumarin under the optimized conditions and gave **1h** and **1i** in high yields (Table 2, entries 8 and 9).

Table 2 SBPPSP-catalyzed synthesis of dihydropyrano[*c*]chromene derivatives

Entry	Ar	Product	Time (min)	Isolated yield (%)	Mp (°C)		
					Reported	This work	
1	C ₆ H ₅ –		1a	12	92	258–260 [17]	256–258
2	4-Cl-C ₆ H ₄ –		1b	10	95	263–265 [20]	252–255
3	3-Cl-C ₆ H ₄ –		1c	10	91	241–243 [24]	246–248
4	4-Br-C ₆ H ₄ –		1d	10	90	254–256 [24]	247–249
5	3-O ₂ N-C ₆ H ₄ –		1e	10	94	266–267 [17]	262–264

(To be continued)

Table 2 (Continued)

Entry	Ar	Product	Time (min)	Isolated yield (%) ^b	Mp (°C)		
					Reported	This work	
6	4-O ₂ N-C ₆ H ₄ –		1f	8	95	259–261 [17]	258–260
7	2-O ₂ N-C ₆ H ₄ –		1g	10	91	—	258–260
8	4-Me-C ₆ H ₄ –		1h	12	90	253–255 [20]	259–260
9	3,4,5,–(MeO) ₃ -C ₆ H ₂ –		1i	12	93	—	236–238
10	4-HO-C ₆ H ₄ –		1j	10	92	266–268 [20]	260–263
11	3-HO-C ₆ H ₄ –		1k	12	93	—	269–270

These results clearly indicate that the reactions can tolerate a wide range of differently substituted aldehydes.

Encouraged by these results, we tried to extend the scope of the catalytic activity of SBPPSP to condensation reactions of 4-hydroxycoumarins and aromatic aldehydes to afford biscoumarin derivatives (Scheme 3).

The desired 3,3'-(4-chlorophenylmethylene)-bis(4-hydroxycoumarin) **4b** was obtained in 95% yield after 15 min by condensation of 2 mmol of 4-hydroxycoumarin with 1 mmol of 4-chlorobenzaldehyde in the presence of 0.06 g of SBPPSP catalyst in aqueous ethanol (1:1, v/v) under reflux. The condensation under solvent-free conditions yielded 80% of pure **4b** in 40 min. A series of biscoumarins with different substituents were successfully prepared from different aromatic aldehydes bearing electron-withdrawing and electron-donating groups and 4-hydroxycoumarin in aqueous ethanol under reflux conditions. The results are listed in

Table 3.

A plausible mechanism in the presence of a base, according to Khurana et al. [19], is shown in Scheme 4. The alpha-cyanocinnamionitrile formed initially by Knoevenagel condensation in the presence of a solid base undergoes subsequent reactions with the alpha-hydroxy of 4-hydroxycoumarin in the presence of a solid base to give the desired product.

The possibility of recycling the catalyst was examined using the model reaction under the optimized conditions. Upon completion, the reaction mixture was filtered and the remaining solid was washed with hot ethanol, dried in air, and the catalyst was reused in the next reaction. The recycled catalyst could be reused five times in the presence of SBPPSP without any additional treatment. No appreciable

Scheme 3. SBPPSP-catalyzed synthesis of biscoumarin derivatives.

Table 3 SBPPSP-catalyzed synthesis of biscoumarin derivatives

Entry	Ar	Product	Time (min)	Isolated yield (%)	Mp (°C)		
					Reported	This work	
1	C ₆ H ₅ –		4a	15	92	233–234 [24]	230–232
2	4-Cl-C ₆ H ₄ –		4b	15	95	258–259 [25]	257–259
3	4-Br-C ₆ H ₄ –		4c	15	91	269–270 [18]	266–268
4	4-F-C ₆ H ₄ –		4d	15	90	220–22 [24]	213–215
5	3-O ₂ N-C ₆ H ₄ –		4e	15	94	213–215 [22]	212–215
6	4-O ₂ N-C ₆ H ₄ –		4f	15	95	237–238 [21]	232–234
7	4-NC-C ₆ H ₄ –		4g	10	95	—	260–262
8	4-Me-C ₆ H ₄ –		5h	30	90	270–271 [23]	269–270
9	4-MeO-C ₆ H ₄ –		4i	20	90	253–254 [23]	249–250

(To be continued)

Table 3 (Continued)

Entry	Ar	Product	Time (min)	Isolated yield (%)	Mp (°C)	
					Reported	This work
10	3,4,5-(MeO) ₃ -C ₆ H ₂ -		30	93	—	245–246
11	4-HO-C ₆ H ₄ -		20	92	—	228–230

loss of catalytic activity of SBPPSP was observed (Fig. 3). The possibility of recycling the catalyst was also examined in the synthesis of biscoumarins via the condensation reaction of 4-chlorobenzaldehyde and 4-hydroxycoumarin under the optimized conditions.

Scheme 4. Plausible mechanism for synthesis of chromene derivatives.

Fig. 3. Recyclabilities of SBPPSP in the synthesis of **1b** (10 min) and **4b** (15 min) under the optimized conditions.

3 Conclusions

In conclusion, we have shown that SBPPSP, which can be prepared from commercially available and cheap starting materials, efficiently catalyzed the synthesis of 3,4-dihydropyrano[*c*]chromenes and biscoumarins. The mild reaction conditions, simplicity of the procedure, and reusability of the catalyst offer improvements over many existing methods.

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