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Synthesis of 4,4′-(arylmethylene)bis(1*H*-pyrazol-5-ols) via multi-component reactions by using silica-bonded sulfamic acid derivatives

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ABSTRACT

The one-pot, multi-component synthesis of 4,4′-(arylmethylene)bis(1*H*-pyrazol-5-ols) by tandem Knoevenagel-Michael reaction of phenylhydrazine, ethyl acetoacetate and aldehydes in the presence of silica-bonded *N*-propylpiperazine sulfamic acid (SBPPSA) as a recyclable solid acid catalyst was reported. SBPPSA showed much the same efficiency when used in consecutive reaction runs.

Keywords: *Silica-bonded N-propylpiperazine sulfamic acid, Catalyst, Aldehydes, 4,4'-(Arylmethylene)bis(1H-pyrazol-5-ols), Multi-component reactions.*

1. Introduction

Multi-component reactions (MCRs) comply with the principle of green chemistry in terms of economy of steps as well as many of the stringent criteria of an ideal organic synthesis. The rapid assembly of molecular diversity utilizing multi-component reaction has received a great deal of attention, most notably for the construction of heterocyclic ′drug-like′ libraries [1-3].

The pyrazolones and bis-pyrazolones were paid much attention for their various biological activities such as selective COX-2 inhibitory [4], antitumor [5,6], and cytokine inhibitors [7]. Bis-pyrazolones can be used as antidepressant [8], gastric secretion stimulatory [9], antibacterial [10], and antifilarial agents [11]. Moreover, 4,4′-(arylmethylene)bis(1H-pyrazzol-5-ols) are applied as pesticides [12], fungicides [13], and dyestuffs [14]. In recent years, different reagents were applied for the synthesis of 4,4′-(arylmethylene)bis(3-methyl-1-phenyl-pyrazol-5-ols) derivatives, some of them including condensation reaction between arylaldehydes and two equivalents of 5-methyl-2-phenyl-2,4-dihydro-3H-pyrazol-3-one [15-25].

Herein, we prepared silica-bonded *N*-propylpiperazine sulfamic acid (SBPPSA) according to our previously reported procedure [26] (Scheme 1) and used as heterogeneous solid acid catalyst for the synthesis of 4,4′-alkylmethylene-bis(3-methyl-5-pyrazolones).

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2. Experimental

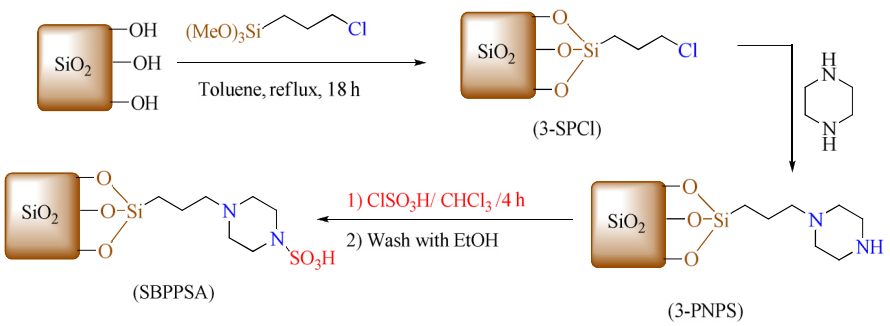
2.1. General

Chemicals were purchased from Fluka, Merck and Aldrich. IR spectra were run on a Shimadzu Infra Red Spectroscopy FT-IR-8000. The ^{1}H and ^{13}C NMR was run on Bruker Avance (DRX 500 MHz, 400 MHz and 300 MHz) instruments in DMSO-d_6. Results are reported in ppm. Melting points were recorded on a SMP1 Melting Point apparatus in open capillary tubes and are uncorrected. Reaction progress was followed by TLC using silica gel SILG/UV 254 plates. All the products were characterized by comparison of their IR, ^{1}H NMR and ^{13}C NMR spectroscopic data and their melting points with reported values [15-25].

2.2. Catalyst Preparation

2.2.1. Synthesis of silica-bonded propylpiperazine sulfamic acid (SBPPSA)

To a magnetically stirred mixture of 3-piperazine-N-propylsilica (3-PNPS) (25 g) in $CHCl_3$ (50 mL), chlorosulfonic acid (25 mL) was added dropwise at 0 ˚C over 2 h. After the addition was complete, the mixture was stirred for another 2 h and then, the mixture was filtered and washed with ethanol (50 mL) and dried at room temperature to afford silica-bonded propylpiperazine sulfamic acid (SBPPSA) as a cream powder (26.8 g). Elemental analysis showed the S content to be 2.85%; C, 8.70%; H, 2.4%; N, 2.1%. The number of H^+ sites of SBPPSA was determined



Scheme 1. Preparation of silica-bonded *N*-propylpiperazine sulfamic acid (SBPPSA).

by pH-ISE conductivity titration (Denver Instrument Model 270) and found to be 1.25 H^+ sites per 1 g of solid acid at 25 °C (pH = 2.30).

2.3. General procedure for the synthesis of 4,4′-(arylmethylene)bis(1H-pyrazol-5-ols)

To a mixture of phenylhydrazine (2 mmol), ethyl acetoacetae (2 mmol), and aldehyde (1 mmol), catalyst SBPPSP (0.07 g, equal to 0.087 mmol of H^+) were added and heated under solvent-free conditions at 80 °C. After completion of the reaction, as indicated by TLC, ethanol (20 mL) was added and filtered. The remaining was washed with warm ethanol (2 × 20 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.

The spectral data

4,4′-(Phenylmethylene)bis(3-methyl-1-phenyl-1H-pyrazol-5-ol) (Table 2, entry 1): IR (KBr, cm^{-1}): 3400, 3080, 2900, 1593, 1494, 1410, 1275, 1020, 730, 690; ^{1}H NMR (300 MHz, DMSO-d_6, ppm) δ: 2.32 (s, 6H), 4.96 (s, 1H), 7.17-7.27 (m, 7H), 7.44 (t, *J* = 7.7 Hz, 4H), 7.71 (d, *J* = 7.9 Hz, 4H), 12.27 (br, 1H, OH), 13.96 (br, 1H, OH). ^{13}C NMR (75 MHz; DMSO-d_6, ppm) δ: 18.54, 33.13, 120.52, 125.55, 125.88, 127.17, 128.12, 128.90, 142.22, 146.29.

4,4′-[(4-Methylphenyl)methylene]bis(3-methyl-1-phenyl-1H-pyrazol-5-ol) (Table 2, entry 2): IR (KBr, cm^{-1}): 3440, 3075, 3830, 1590, 1495, 1408, 1294, 1020, 800, 744, 688; ^{1}H NMR (300 MHz; DMSO-d_6, ppm) δ: 2.24 (s, 3H), 2.30 (s, 6H), 4.90 (s, 1H), 7.07 (d, *J* = 8.3 Hz, 2H), 7.13 (d, *J* = 8.1 Hz, 2H), 7.24 (t, *J* = 7.4 Hz, 2H), 7.44 (t, *J* = 7.7 Hz, 4H), 7.70 (d, *J* = 7.9 Hz, 4H), 12.28 (br, 1H, OH), 13.93 (br, 1H, OH). ^{13}C NMR (75 MHz; DMSO-d_6 ppm) δ: 18.55, 20.50, 32.39, 114.85, 120.47, 125.49, 127.05, 128.08, 128.89, 134.79, 139.13, 146.18, 155.49.

4,4′-[(4-isopropylphenyl)methylene]bis(3-methyl-1-phenyl-1H-pyrazol-5-ol) (Table 2, entry 3): IR (KBr, cm^{-1}): 3435, 3080, 2920, 2830, 1590, 1495, 1408, 1380, 1365, 1294, 1020, 779, 744, 688. ^{1}H NMR (500 MHz, DMSO-d_6, ppm) δ: 1.16 (d, 6H, *J* = 6.9 Hz), 2.31 (s, 6H), 2.79-2.85 (m, 1H), 4.90 (s, 1H), 7.13 (d, 2H, *J* = 8.2 Hz), 7.18 (d, 2H, *J* = 8.1 Hz), 7.23 (t, 2H, *J* = 7.3 Hz), 7.43 (t, 4H, *J* = 7.3 Hz), 7.72 (d, 4H, *J* = 7.9 Hz), 12.30 (br, 1H, OH), 14.03 (s, 1H, OH). ^{13}C NMR (125 MHz, DMSO-d_6, ppm) δ: 12.51, 24.78, 33.70, 33.84, 121.39, 126.40, 126.93, 127.93, 129.77, 140.57, 146.72, 147.14.

4,4′-[(4-Methylthiophenyl)methylene]bis(3-methyl-1-phenyl-1H-pyrazol-5-ol) (Table 2, entry 4): IR (KBr, cm^{-1}): 3425, 3085, 2918, 1592, 1495, 1186, 779, 748; ^{1}H NMR (400 MHz, DMSO-d_6, ppm) δ: 2.3 (s, 6H), 2.43 (s, 3H), 4.92 (s, 1H), 7.18 (s, 4H), 7.25 (t, *J* = 7.3 Hz, 2H), 7.44 (t, *J* = 7.8 Hz, 4H), 7.70 (d, *J* = 7.8 Hz, 4H), 12.47 (br, 1H, OH), 13.92 (br, 1H, OH). ^{13}C NMR (100MHz, DMSO-d_6, ppm) δ: 14.96, 31.86, 120.45, 120.55, 126.88, 127.82, 128.92, 129.71, 131.41, 136.44, 143.57, 146.97, 147.57.

4,4′-[(3,4-Dimethoxyphenyl)methylene]bis(3-methyl-1-phenyl-1H-pyrazol-5-ol) (Table 2, entry 5): IR (KBr, cm^{-1}): 3428, 3085, 2920, 1580, 1508, 1410, 1133, 1025, 804, 685; ^{1}H NMR (400 MHz, DMSO-d_6, ppm) δ: 2.33 (s, 6H), 3.67 (s, 3H), 3.71 (s, 3H), 4.90 (s, 1H), 6.82-6.88 (m, 2H), 6.91 (d, *J* = 1.8 Hz, 1H), 7.25 (t, *J* = 7.3 Hz, 2H), 7.45 (t, *J* = 7.9 Hz, 4H), 7.72 (d, *J* = 7.6 Hz, 4H), 12.38 (br, 1H, OH), 14.06 (br, 1H, OH). ^{13}C NMR (100 MHz, DMSO-d_6, ppm) δ: 11.62, 32.88, 55.42, 55.47, 111.52, 111.64, 119.26, 120.56, 125.55, 134.88, 146.15, 147.19, 148.35.

4,4′-[(3,4,5-Trimethoxyphenyl)methylene]bis(3-methyl-1-phenyl-1H-pyrazol-5-ol) (Table 2, entry 6). IR (KBr, cm^{-1}): 3447, 3085, 2885, 1585, 1490, 1443, 1410, 1318, 1262, 1122, 898, 850, 790, 690; ^{1}H NMR (500 MHz, DMSO-d_6, ppm) δ: 2.33 (s, 6H), 3.62 (s, 3H), 3.69 (s, 6H), 4.85 (s, 1H), 6.69 (s, 2H), 7.24 (t, *J* = 7.3 Hz, 2H), 7.43 (t, *J* = 7.8 Hz, 4H), 7.71 (d, *J* = 7.9 Hz, 4H), 14.29 (s, 1H, OH). ^{13}C NMR (125 MHz, DMSO-d_6) δ: 12.61, 34.76, 56.70, 60.80, 105.81, 121.59, 126.45, 129.78, 136.86, 138.29, 139.62, 147.03, 153.42.

4,4′-[(2-Chlorophenyl)methylene]bis(3-methyl-1-phenyl-1H-pyrazol-5-ol) (Table 2, entry 7): IR (KBr, cm^{-1}): 3450, 3070, 2910, 1610, 1555, 1495, 1395, 1360, 1300, 835, 740, 690 cm-1; ^{1}H NMR (500 MHz, DMSO-d_6, ppm) δ: 2.29 (s, 6H), 5.14 (s, 1H), 7.22-7.33 (m, 4H), 7.40 (d, J = 7.8 Hz, 1H), 7.44 (t, J = 7.6 Hz, 4H), 7.70 (d, J = 7.6 Hz, 4H), 7.80

(d, J = 7.1 Hz, 1H), 12.65 (br, 1H, OH), 13.92 (br, 1H, OH). ^{13}C NMR (100 MHz; DMSO-d6, ppm) δ: 12.08, 32.41, 120.67, 123.62, 126.92, 128.05, 128.93, 129.45, 130.32, 135.94, 137.36, 140.60, 141.18.

4,4′-[(2,4-Dichlorophenyl)methylene]bis(3-methyl-1-phenyl -1H-pyrazol-5-ol) (Table 2, entry 8): IR (KBr, cm^{-1}): 3430, 3080, 2920, 1592, 1498, 1379, 1100, 748, 690; ^{1}H NMR (400 MHz, DMSO-d$_6$, ppm) δ: 2.28 (s, 6H), 5.09 (s, 1H), 7.25 (t, *J* = 7.3 Hz, 2H), 7.40-7.46 (m, 5H), 7.56 (d, *J* = 2.3 Hz, 1H) 7.69 (d, *J* = 8.6 Hz, 4H), 7.75 (d, *J* = 8.6 Hz, 1H), 12.43 (br, 1H, OH), 13.82 (br, 1H, OH). ^{13}C NMR (100 MHz, DMSO-d$_6$) δ: 12.03, 31.35, 120.59, 126.98, 128.85, 128.93, 131.42, 131.64, 132.89, 138.45, 140.45.

4,4′-[(4-Nitrophenyl)methylene]bis(3-methyl-1-phenyl-1H-pyrazol-5-ol) (Table 2, entry 9): IR (KBr, cm^{-1}): 3440, 3090, 2920, 1595, 1495, 1410, 1340, 744, 689; ^{1}H NMR (400 MHz; DMSO-d$_6$, ppm) δ: 2.28 (s, 6H), 5.06 (s, 1H), 7.18 (t, *J* = 7.1 Hz, 2H), 7.38 (t, *J* = 7.3 Hz, 4H), 7.45 (d, *J* = 8.3 Hz, 2H), 7.64 (d, *J* = 7.8 Hz, 4H), 8.10 (d, *J* = 8.6 Hz, 2H), 13.81 (br, 1H, OH). ^{13}C NMR (100 MHz; DMSO-d$_6$, ppm) δ: 11.62, 34.45, 121.91, 124.65, 127.03, 129.92, 130.25, 147.20, 147.58, 151.63.

4,4′-[(3-Nitrophenyl)methylene]bis(3-methyl-1-phenyl-1H-pyrazol-5-ol) (Table 2, entry 10): IR (KBr, cm^{-1}): 3420, 3085, 2910, 1595, 1495, 1340, 758, 735, 692, 598; ^{1}H NMR (400 MHz; DMSO-d$_6$, ppm) δ: 2.35 (s, 6H), 5.14 (s, 1H), 7.26 (t, *J* = 7.3 Hz, 2H), 7.45 (t, *J* = 7.6 Hz, 4H), 7.60 (t, *J* = 8.3 Hz, 1H), 7.68-7.74 (m, 5H), 8.06-8.10 (m, 2H), 13.91 (br, 1H, OH). ^{13}C NMR (100 MHz; DMSO-d$_6$, ppm) δ: 11.52, 32.80, 120.63, 121.21, 121.70, 125.78, 125.81, 128.98, 129.71, 134.34, 137.39, 144.56, 146.30, 147.72.

4,4′-[(4-Hydroxyphenyl)methylene]bis(3-methyl-1-phenyl-1H-pyrazol-5-ol) (Table 2, entry 11): IR (KBr, cm^{-1}): 3420, 3150, 3090, 2920, 1593, 1492, 1410, 1270, 744, 690; ^{1}H NMR (300 MHz, DMSO-d$_6$, ppm) δ: 2.30 (s, 6H), 4.85 (s, 1H), 6.67 (d, 2H, *J* = 7.7 Hz), 7.05 (d, 2H, *J* = 7.2 Hz), 7.24 (t, 2H, *J* = 5.0 Hz), 7.42-7.45 (m, 4H), 7.66-7.77 (m, 4H), 9.19 (s, 1H, OH), 13.96 (br, 1H, OH). ^{13}C NMR (75 MHz, DMSO-d$_6$, ppm) δ: 18.55, 32.39, 114.85, 120.47, 125.49, 128.08, 128.89, 132.27, 137.39, 146.18, 155.49.

4,4′-[(3-Hydroxyphenyl)methylene]bis(3-methyl-1-phenyl-1H-pyrazol-5-ol) (Table 2, entry 12): IR (KBr, cm^{-1}): 3410, 3150, 3080, 2920, 1592, 1495, 1270, 1168, 1042, 750, 690; ^{1}H NMR (400 MHz, DMSO-d$_6$, ppm) δ: 2.42 (s, 6H), 4.98 (s, 1H), 6.67 (dd, J_1 = 8.1 Hz, J_2 = 1.5 Hz, 1H), 6.76-6.80 (m, 2H), 7.17 (t, *J* = 7.8 Hz, 1H), 7.36 (t, *J* = 7.3 Hz, 2H), 7.56 (t, *J* = 7.8 Hz, 4H), 7.83 (d, *J* = 7.8 Hz, 4H), 9.34 (s, 1H, OH), 14.08 (br, 1H, OH). ^{13}C NMR (100 MHz, DMSO-d$_6$, ppm) δ: 11.77, 32.52, 114.20, 119.54, 120.48, 128.92, 128.97, 132.72, 137.47, 143.67, 147.04, 157.17.

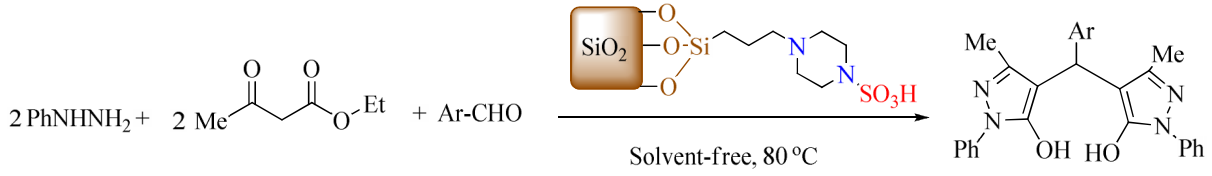
4,4′-[(2-Hydroxyphenyl)methylene]bis(3-methyl-1-phenyl-1H-pyrazol-5-ol) (Table 2, entry 13). ^{1}H NMR (500 MHz, DMSO-d$_6$, ppm) δ: 2.28 (s, 6H), 5.16 (s, 1H), 6.70 (t, *J* = 7.5 Hz, 1H), 6.74 (d, *J* = 7.5 Hz, 1H), 6.96 (t, *J* = 7.0 Hz, 1H), 7.22 (t, *J* = 7.3 Hz, 2H), 7.42 (t, *J* = 7.9 Hz, 4H), 7.57 (d, *J* = 7.2 Hz, 1H), 7.71 (d, *J* = 7.8 Hz, 4H). ^{13}C NMR (125 MHz, DMSO-d$_6$, ppm) δ: 12.73, 28.15, 115.66, 119.42, 121.37, 126.18, 127.65, 129.71, 147.16, 154.68.

4,4′-[(2-Furyl)methylene]bis(3-methyl-1-phenyl-1H-pyrazol-5-ol) (Table 2, entry 14): IR (KBr, cm^{-1}): 3420, 3080, 2920, 1595, 1490, 1410, 1284, 779, 690; ^{1}H NMR (400 MHz, DMSO-d$_6$, ppm) δ: 2.31 (s, 6H), 4.99 (s, 1H), 6.12-6.14 (m, 1H), 6.34-6.36 (m, 1H), 7.25 (t, *J* = 6.0 Hz, 2H), 7.43-7.51 (m, 5H), 7.71 (d, *J* = 8.0 Hz, 4H), 12.46 (br, 1H, OH), 13.85 (s, 1H, OH). ^{13}C NMR (100MHz, DMSO-d$_6$, ppm) δ: 11.48, 28.22, 106.11, 109.88, 110.34, 120.43, 120.55, 125.60, 128.91, 131.92, 141.54.

3. Results and Discussion

In continuation of our studies to develop the new catalysts for organic transformations [23-34], herein we wish to report a valid and an efficient procedure for the synthesis of 4,4′-alkylmethylene-bis(3-methyl-5-pyrazolones) *via* three-component condensation of aldehydes, phenyl hydrazine and ethyl acetoacetate in the presence of SBPPSA as an inexpensive solid acid catalyst (Scheme 2).

In a primary study, the reaction of phenyl hydrazine, ethyl acetoacetate and benzaldehyde in the presence of a catalytic amount of SBPPSA under solvent-free conditions at 80 °C was investigated and the corresponding bis-pyrazolone was afforded in high yield (Scheme 2, Table 1). A blank experiment without catalyst gave very low yield after 24 h (Table 1, entry 1). Obviously, SBPPSA is an important component of the reaction. As indicated in Table 1, the best result has been obtained with an amount of 0.07 g (equal to 0.087 mmol of H^+) SBPPSA in terms of reaction time and isolated yield.



Scheme 2. Three component condensation reaction of phenylhydrazine, ethyl acetoacetate with aldehydes catalyzed by SBPPSA.

Table 1. Condensation reaction of phenyl hydrazine, ethyl acetoacetate and benzaldehyde in the presence of different amounts of SBPPSA under solvent-free conditions.[a]

Entry	Catalyst	Catalyst loading (g)	Time (min)	Yield (%)[b]
1	No catalyst	-	24 h	<10
2	SBPPSA	0.03 (0.037 mmol of H^+)	160	77
3	SBPPSA	0.05 (0.063 mmol of H^+)	120	82
4	SBPPSA	0.07 (0.087 mmol of H^+)	45	93
5	SBPPSA	0.10 (0.125 mmol of H^+)	45	94

[a]Reaction conditions: phenyl hydrazine (2 mmol), ethyl acetoacetate (2 mmol), benzaldehyde (1 mmol), solvent-free at 80 °C.
[b]Isolated Yield.

Using the optimized conditions, the catalytic efficiency of SBPPSA was also observed for other substituted aromatic aldehydes (Scheme 2 and Table 2). As shown in Table 2, a series of benzaldehydes including electron-donating or electron-withdrawing groups, i.e. methyl, iso-propyl, methylthio, and 3,4-dimethoxy benzaldehyde (Table 2, entries 2-6) or 4-nitro and 3-nitro benzaldehyde (Table 2, entries 9 and 10), were condensed into the corresponding 4,4′-(arylmethylene) bis (3-methyl-1-phenyl-1H-pyrazol-5-ols) **3b-3f** and **3i-3j** in very good yields. Hydroxy benzaldehydes were treated with phenyl hydrazine and ethyl acetoacetate gave into corresponding products **3k-3m** in 88-92% yield (Table 2, entries 11-13). Heteroaromatic aldehydes such as furfural (Table 2, entry 14) were reacted with phenyl hydrazine and ethyl acetoacetate gave the corresponding product **3n** in 80% yield respectively.

Finally, a comparative study of SBPPSA with other recently reported catalysts for condensation of benzaldehyde with 3-methyl-l-phenyl-5-pyrazolone as a model compound was made which revealed that SBPPSA is an equally efficient and also better than other catalysts in view of time and yield (Table 3). Also, the results showed that SBPPSA is more efficient catalyst in comparison with our recent published method for the synthesis of 4,4′-(arylmethylene)bis(3-methyl-1-phenyl-1H-pyrazol-5-ols) catalyzed by silica-bonded ionic liquid [Sipim]HSO_4 (Table 3 entry 5) [35].

The condensation reaction between phenyl hydrazine, ethyl acetate and benzaldehyde was examined for the possibility of recycling SBPPSA under the optimized conditions. After completion, the reaction mixture was washed with warm

Table 2. Preparation of 4,4′-(arylmethylene)bis (3-methyl-1-phenyl-1H-pyrazol-5-ols) derivatives catalyzed by SBPPSA under solvent-free conditions at 80 °C. [a]

Entry	Ar (**1**)	Product	Time (min)	Yield%[b]	m.p. (°C)	
					Found	Reported [Ref.]
1	C_6H_5-	3a	45	93	170-172	171-172[19]
2	4-Me-C_6H_4-	3b	50	91	202-204	203 [15]
3	4-iso-Pr-C_6H_4-	3c	55	93	132-134	132-134[25]
4	4-MeS-C_6H_4-	3d	60	91	200-202	201-203[23]
5	3,4-$(MeO)_2$-C_6H_3-	3e	60	90	195-197	195-197[24]
6	3,4,5-$(MeO)_3$-C_6H_2-	3f	60	89	194-196	195-197[25]
7	2-Cl-C_6H_4-	3g	55	89	235-237	236-237[19]
8	2,4-$(Cl)_2$-C_6H_3-	3h	60	88	227-229	228-230[19]
9	4-O_2N-C_6H_4-	3i	35	91	228-230	230-232[19]
10	3-O_2N-C_6H_4-	3j	40	90	151-153	149-150[19]
11	4-HO-C_6H_4-	3k	60	92	155-157	152-153[19]
12	3-HO-C_6H_4-	3l	60	91	165-168	165-168[23]
13	2-HO-C_6H_4-	3m	60	88	227-229	230-231[20]
14	2-Furyl-	3n	60	80	189-191	181-183[21]

[a]Reaction conditions: phenyl hydrazine (2 mmol), ethyl acetoacetate (2 mmol), benzaldehyde (1 mmol), solvent-free conditions at 80 °C.
[b]Isolated yield.

Table 3. Comparison of the result of condensation reaction for the synthesis of 4,4′-(phenylmethylene)bis(3-methyl-1-phenyl-1*H*-pyrazol-5-ols) in the presence of different catalysts based on silica.

Entry	Catalyst	Catalyst loading (g)	Conditions	Time (min)	Yield[a] (%)	Ref.
1	Silica-bonded S-sulfonic acid SBSSA	0.1 (0.033 mmol)	Reflux ethanol	120	80	[23]
2	Montmorillonite K10	0.1	Aqueous ethanol 70 °C	120	60	[24]
3	Silica sulfuric acid	0.08 (0.208 mmol)	Aqueous ethanol 70 °C	360	88	[24]
4	SASPSPE	0.1 (0.034 mmol)	Reflux ethanol	180	90	[25]
5	Silica-bonded ionic liquid [Sipim]HSO_4	0.15 (0.083 mmol)	Reflux ethanol	120	89	[35]
6	SBPPSA	0.07 (equal to 0.087 mmol of H^+)	Solvent-free 80 °C	45	93	This work

[a]Isolated yield.

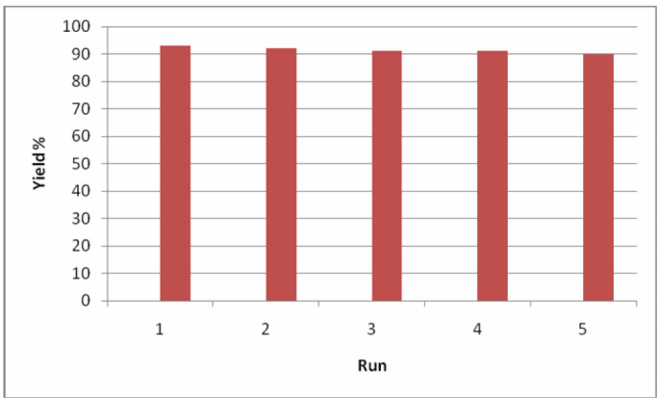


Fig. 1. Recyclability of SBPPSA (0.07 g) in the condensation reaction of phenyl hydrazine (2 mmol), ethyl acetoacetate (2 mmol), and benzaldehyde (1 mmol) under solvent-free conditions at 80 °C. Time = 45 min.

ethanol (3 × 30 mL). The recovered catalyst was washed with diethyl ether, dried and reused for subsequent runs. SBPPSA showed much the same efficiency when used in five consecutive reactions runs (Fig. 1).

4. Conclusion

In conclusion, heterogeneous conditions, solvent-free conditions, easy and clean work-up, high yields and recovery of the catalyst makes this method practical for the synthesis of 4,4′-(arylmethylene) bis (3-methyl-1-phenyl-1*H*-pyrazol-5-ols).

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