Studies on the synthesis of substituted 2-amino-4*H*-benzo[*h*]chromene and 3-amino-1*H*-benzo[*f*]chromene derivatives using base supported ionic liquid like-phase (SILLP) as an efficient green catalyst

Leila Kheirkhah[a], Manouchehr Mamaghani[a]*, Nosrat Ollah Mahmoodi[a], Asieh Yahyazadeh[a] and Seyedeh Saeedeh Mirnezami Ziabari[b]

[a]*Department of Chemistry, Faculty of Sciences, University of Guilan, PO Box 41335-1914, Rasht, Iran*
[b]*Department of Chemistry, Faculty of Sciences, Islamic Azad University, Rasht Branch, PO Box 41335-3516, Rasht, Iran*

The synthesis of several substituted 2-amino-4*H*-benzo[*h*]chromene and 3-amino-1*H*-benzo[*f*]chromene derivatives was carried out using a one-pot three-component reaction of an arylaldehyde, malononitrile and a naphthol in H_2O and in the presence of recyclable base supported ionic liquid like-phase as an efficient green catalyst.

Keywords: 2-aminobenzo[*h*]chromene, 3-aminobenzo[*f*]chromene, three-component reaction, base supported ionic liquid like-phase (SILLP), naphthol

2-Aminochromenes are an important class of heterocyclic compounds with important biological activities and pharmacological properties. Fused-ring chromenes are biologically interesting compounds showing a wide spectrum of activities, such as antimicrobial,[1] mutagenicitical,[2] mitogen-activated protein kinase-activated protein kinase 2 inhibitory,[3] antiproliferative,[4] sex pheromonal,[5] antitumoural[6] and antioxidant activities.[7]

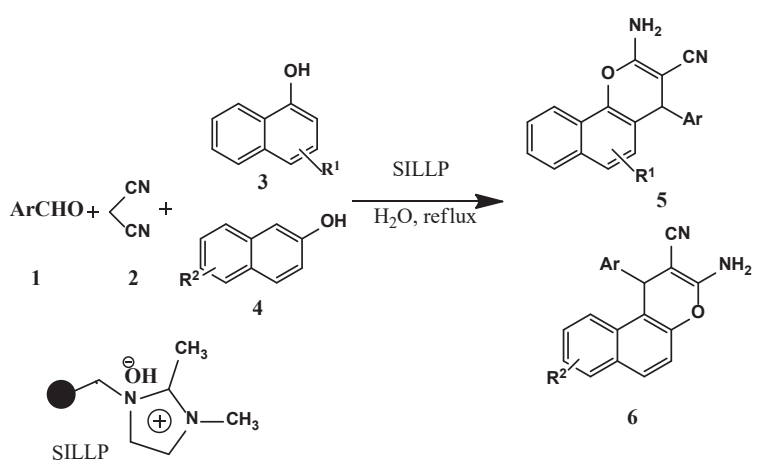
Traditional methods have been reported for the synthesis of 2-aminobenzo[*h*]chromene and 3-aminobenzo[*f*]chromene derivatives by condensation of α-naphthol or β-naphthol, an aldehyde and malononitrile using different homogeneous or heterogeneous catalysts, such as cetyltrimethyl-ammonium chloride/bromide,[8,9] triethylbenzylammonium chloride,[10] tetrabutylammonium bromide[11] and benzyl[2-(dimethylamino) ethyl]dimethylammonium chloride.[12] Although each of these procedures has its own merits, some methods require the use of a hazardous amine-based catalyst and expensive catalysts, and have long reaction times, harsh reaction conditions, low yields, tedious work-up processes, environmental disposal problems or use organic solvents. Thus, we report a more convenient and practical method for the syntheses of 2-aminobenzo[*h*]chromene and 3-aminobenzo[*f*]chromene derivatives using base supported ionic liquid like-phase (SILLP)[13] as a recyclable solid supported heterogeneous catalyst in water. Water is the cheapest and most abundant non-toxic chemical in nature. Aqua-mediated reactions have received considerable attention in organic synthesis due to environmental safety reasons. Reactions in aqueous media offer many advantages, such as simple operation and high efficiency, in many organic reactions that involve water soluble substrates and reagents.[14,15] These advantages become even more attractive if such reactions can be conducted using ionic liquids in aqueous media.

Results and discussion

Ionic liquids have attracted increasing interest in the context of green synthesis in recent years. They have a unique combination of chemical and physical properties, including nonvolatility, nonflammability, thermal stability and controlled miscibility. They are the solvents of choice for a large array of organic reactions and can perform as a catalyst at the same time.[16–22]

With respect to our continued interest in developing benign methods for the synthesis of biologically important products,[23–28] we report a simple and high-yielding protocol for the synthesis of 2-amino-2-chromenes using SILLP as an efficient and recyclable heterogeneous base catalyst (Scheme 1).

In a preliminary experiment, to optimise the reaction conditions, SILLP was synthesised using Merrifield resin (1% cross linked, 200–400 mesh, 1.0–1.3 mmol g^{-1}) and the procedure employed by Luis and coworkers.[13] A one-pot three-component reaction of equimolar amounts of



Ar = 4-ClC_6H_4, 4-BrC_6H_4, 3-BrC_6H_4, 4-MeC_6H_4, 4-$MeOC_6H_4$, 2-thienyl, 2-furyl, 2-$O_2NC_6H_4$, 3-$O_2NC_6H_4$, 4-$O_2NC_6H_4$, 4-FC_6H_4,..
R^1 = H, 4-Cl; R^2 = H, 6-Br

Scheme 1 Synthesis of 2-amino- and 3-aminochromene derivatives using SILLP.

* Correspondent. E-mail: m-chem41@guilan.ac.ir; mchem41@gmail.com

4-chlorobenzaldehyde (**1**), malononitrile and α-naphthol in the presence of SILLP (0.1 g $mmol^{-1}$ substrate) in refluxing water was selected as the model reaction. The reaction furnished the desired 2-aminochromene **5a** (Table 1, entry 1) in 80% yield. The effect of various solvents, such as H_2O, EtOH, THF, CH_3CN, CH_2Cl_2, DMF and 1,4-dioxane, and different temperatures was also examined, with water selected as the solvent of choice at refluxing temperature. Under optimised conditions, various arylaldehydes and naphthol derivatives were evaluated and the results are presented in Table 1. As shown in Table 1, aromatic aldehydes with electron-donating and electron-withdrawing groups were rapidly condensed with malononitrile and various naphthols in the presence of SILLP and afforded the corresponding aminochromenes in high yield (80–97%) and short reaction time (10–20 min).

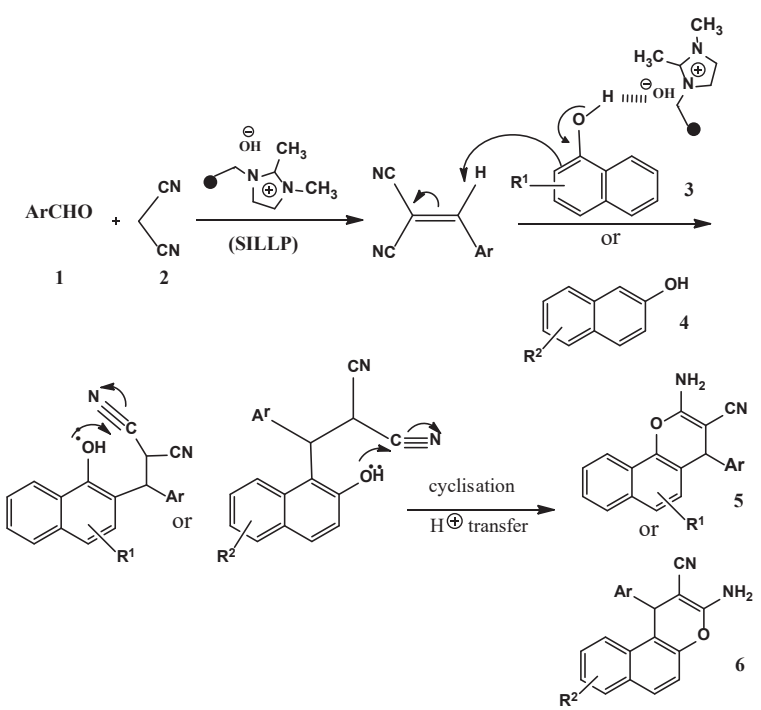
A plausible mechanism for the formation of products **5** and **6** is presented in Scheme 2, which proceeds through a Knoevenagel condensation of an arylaldehyde (**1**) and malononitrile (**2**) followed by Michael addition of a naphthol (**3** or **4**) to furnish the desired products.

Table 1 2-Aminochromene derivatives using SILLP under optimised conditions

Entry	Ar	Naphthol	Product	Time/min	Yield/%[a,b]	Melting point/°C
1	4-ClC_6H_4	α-naphthol	5a	18[a]	80	233–235 (lit.[29] 231–233)
2	4-$O_2NC_6H_4$	α-naphthol	5b	20[a]	82	239–241(lit.[29] 239.5–241)
3	4-BrC_6H_4	α-naphthol	5c	15[a]	85	255–257
4	4-$CH_3OC_6H_4$	α-naphthol	5d	10[a]	87	195–197 (lit.[30] 195–196)
5	4-$CH_3C_6H_4$	α-naphthol	5e	15[a]	86	206–208 (lit.[31] 205–207)
6	C_6H_5	α-naphthol	5f	10[a]	97	222–224 (lit.[32] 218–219)
7	2-$NO_2C_6H_4$	α-naphthol	5g	20[a]	94	232–234 (lit.[32] 230–232)
8	3-$O_2NC_6H_4$	α-naphthol	5h	15[a]	93	215–217 (lit.[29] 214.5–216)
9	3-BrC_6H_4	α-naphthol	5i	10[a]	90	236–238
10	4-FC_6H_4	α-naphthol	5j	20[a]	93	231–233 (lit.[32] 234–236)
11	3-$O_2NC_6H_4$	4-chloro-α-naphthol	5k	10[a]	91	220–221
12	4-$O_2NC_6H_4$	4-chloro-α-naphthol	5l	15[a]	96	229–231
13	2-thienyl	4-chloro-α-naphthol	5m	10[a]	91	235–236
14	2-furyl	4-chloro-α-naphthol	5n	10[a]	90	227–229
15	2-furyl	α-naphthol	5o	12	87	170–171 (lit.[32] 169–172)
16	C_6H_5	β-naphthol	6a	10[a]	93	285–287 (lit.[32] 288–289)
17	4-FC_6H_4	β-naphthol	6b	12[a]	90	230–232 (lit.[32] 232–233)
18	4-$CH_3C_6H_4$	β-naphthol	6c	15[a]	85	268–270 (lit.[31] 270–272)
19	2-furyl	β-naphthol	6d	10[a]	85	224–226 (lit.[32] 225–226)
20	4-ClC_6H_4	β-naphthol	6e	15	83	206–208 (lit.[32] 207–208.5)
21	4-$O_2NC_6H_4$	6-bromo-β-naphthol	6f	13	81	197–199

[a]Isolated yield.

[b]Ratio of aldehyde (1 mmol)/malononitrile (1 mmol)/naphthol (1 mmol)/SILLP (0.1 g); the reaction was accomplished in H_2O at 100 °C.



Scheme 2 A plausible mechanism for the synthesis of **5a–o** and **6a–f**.

Table 2 Comparison of the efficiency of different catalysts in the synthesis of **5f** in refluxing H_2O

Entry	Ar	Catalyst	Time/min	Yield/%[a]
1	C_6H_5	SILLP	10	97 (this work)
2	C_6H_5	[bmim]OH[b]	60	90 (lit.[33])
3	C_6H_5	[bmim][PF_6][c]	120	86 (lit.[34])
4	C_6H_5	$CuSO_4 \cdot 5H_2O$	60	95 (lit.[34])

[a]Isolated yield.

[b]1-Butyl-3-methylimidazolium hydroxide.

[c]1-Butyl-3-methylimidazolium hexafluorophosphate.

The reusability of the catalyst in the abovementioned reactions was also rechecked by using the preparation of **5a** and **6a** as model reactions. After five consecutive runs, the activity of the catalyst remained almost unchanged. After each run, the product mixture was dissolved in EtOH, the catalyst simply filtered off, washed with EtOH, dried and reused for the next four runs without appreciable loss of its catalytic activity.

To show the efficiency of the present method, we have compared our results for the synthesis of 2-aminobenzo[*h*] chromene **5f**, catalysed by SILLP, with other reported protocols in the literature. It is evident from the results in Table 2 that the reaction in the presence of SILLP produces the product in a much shorter reaction time and higher yield.

Conclusion

We have developed an efficient and eco-friendly protocol for the one-pot three-component synthesis of 2-aminobenzo[*h*] chromene and 3-aminobenzo[*f*]chromene derivatives using SILLP. The catalyst is recoverable and the efficiency of the catalyst remains almost unaltered after five cycles. Excellent yields, simple workup, short reaction times, easy recovery of the catalyst and the green nature of the procedure make this methodology attractive for large-scale synthesis.

Experimental

Melting points were measured on an Electrothermal 9100 apparatus. IR spectra were determined on a Shimadzo IR-470 spectrometer. ^{1}H NMR and ^{13}C NMR spectra were recorded on a 400 and 500 MHz Bruker DRX-400 with DMSO-d_6 as solvent and TMS as an internal standard. Chemical shifts are expressed in ppm downfield from TMS. Elemental analyses were performed on a Carlo-Erba EA1110CNNO-S analyser and agreed (within 0.2%) with the calculated values. All chemicals were purchased from Merck and used without further purification. All solvents used were dried and distilled according to standard procedures.

Synthesis of 2-amino-4H-benzo[h]chromene and 3-amino-1H-benzo[f]chromene derivatives (**5a**–**o**, **6a**–**f**)*; general procedure*

A mixture of benzaldehyde **1** (1 mmol), malononitrile **2** (1 mmol), α-naphthol **3** (1 mmol) or β-naphthol (**4**) and SILLP (0.1 g) in water (5 mL) were refluxed for a certain time (monitored by TLC), and the solid product was dissolved in EtOH and filtered off to remove the catalyst. The catalyst was washed with EtOH and the combined organic solution was evaporated under reduced pressure to produce the desired products. The crude products were purified by recrystallisation from DMF–H_2O and washing with cold ethanol. The catalyst was dried and reused for four runs without appreciable loss of its catalytic activity.

*2-Amino-4-(4-bromophenyl)-3-cyano-4*H*-benzo[*h*]chromene* (**5c**): White powder; IR (KBr) (ν_{max} cm^{-1}): 3450, 3333, 3198 (N–H), 2179 (C≡N), 1662 (C=C), 1012 (C–Br), 806, 758 (aromatic C–H bend); ^{1}H NMR (500 MHz, DMSO-d_6): δ 8.25 (1H, d, *J* = 8.32 Hz, ArH), 7.88 (1H, d, *J* = 8.08 Hz, ArH), 7.63 (1H, t, *J* = 7.58 Hz, ArH), 7.59 (1H, d, *J* = 8.52 Hz, ArH), 7.56 (1H, t, *J* = 7.02 Hz, ArH), 7.50 (2H, d, *J* = 8.34 Hz, ArH), 7.21 (2H, d, *J* = 8.34 Hz, ArH), 7.20 (2H, s, NH_2), 7.08 (1H, d, *J* = 8.52 Hz, ArH), 4.93 (1H, s, C–H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 161.0, 145.9, 143.7, 133.6, 132.5, 130.8, 128.6, 127.7, 127.6, 126.9, 124.9, 123.6, 121.6, 121.2, 121.0 118.2, 56.7, 41.2. Anal. calcd for $C_{20}H_{13}BrN_2O$ (377.23): C, 63.68; H, 3.47; N, 7.43; found: C, 63.49; H, 3.32; N, 7.28%.

*2-Amino-4-(3-bromophenyl)-3-cyano-4*H*-benzo[*h*]chromene* (**5i**): White powder; IR (KBr) (ν_{max} cm^{-1}): 3445, 3334, 3190 (N–H), 2189 (C≡N), 1656 (C=C), 1016 (C–Br), 810, 756 (aromatic C–H bend); ^{1}H NMR (500 MHz, DMSO-d_6): δ 8.25 (1H, d, *J* = 8.4 Hz, ArH), 7.92 (d, *J* = 8.0 Hz, ArH), 7.68–7.58 (3H, m, ArH), 7.47–7.44 (2H, m, ArH), 7.33–7.25 (2H, m, ArH), 7.15 (1H, d, *J* = 8.8 Hz, ArH), 4.98 (1H, s, C–H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 160.77, 160.73, 148.87, 143.26, 133.27, 131.51, 130.74, 130.40, 128.19, 127.39, 127.25, 126.50, 124.58, 123.22, 122.45, 121.23, 120.81, 117.68, 56.15, 40.88. Anal. calcd for $C_{20}H_{13}BrN_2O$ (377.23): C, 63.68; H, 3.47; N, 7.43; found: C, 63.51; H, 3.28; N, 7.24%.

*2-Amino-6-chloro-4-(3-nitrophenyl)-3-cyano-4*H*-benzo[*h*]carbonitrile* (**5k**): Yellow powder; IR (KBr) (ν_{max} cm^{-1}): 3369, 3315 (N–H), 2196 (C≡N), 1660 (C=C), 1529, 1352 (NO_2), 857, 811, 762 (aromatic C–H bend); ^{1}H NMR (400 MHz, DMSO-d_6): δ 8.36 (1H, m, ArH), 8.19 (1H, t, *J* =1.8, ArH), 8.16–8.12 (2H, m, ArH), 7.82–7.77 (3H, m, Ar–H), 7.67 (1H, t, *J* = 8.0 Hz, ArH), 7.44 (s, NH_2), 7.40 (1H, s, ArH), 5.22 (1H, s, C–H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 160.7, 160.65, 148.5, 147.7, 142.7, 135.1, 131.0, 129.9, 128.9, 128.3, 126.4, 126.1, 124.4, 124.3, 122.8, 122.6, 122, 120.5, 117.9, 55.7. Anal. calcd for $C_{20}H_{12}ClN_3O_3$ (377.78): C, 63.59; H, 3.20; N, 11.12; found: C, 63.43; H, 3.09; N, 11.04%.

*2-Amino-6-chloro-4-(4-nitrophenyl)-3-cyano-4*H*-benzo[*h*]carbonitrile* (**5l**): Yellow powder; IR (KBr) (ν_{max} cm^{-1}): 3445, 3325, 3202 (N–H), 2191 (C≡N), 1661 (C=C), 1514, 1348 (NO_2), 1109 (C–Cl), 874, 812, 758, 698 (aromatic C–H bend); ^{1}H NMR (500 MHz, DMSO-d_6): δ 8.33 (d, *J* = 7.87 Hz, 1H, ArH), 8.17 (d, *J* = 8.80 Hz, 2H, ArH), 8.03 (d, *J* = 8.50 Hz, 1H, ArH), 7.75–7.68 (m, 2H, ArH), 7.55 (d, *J* = 8.80 Hz, 2H, ArH), 7.42 (s, 2H, NH_2), 7.27 (s, 1H, ArH), 5.13 (s, 1H, C–H); ^{13}C NMR (125 MHz, DMSO-d_6): δ 161.0, 153.2, 147.5, 143.2, 130.4, 129.9, 129.3, 128.7, 126.8, 126.5, 125.0, 124.8, 124.7, 122.4, 120.8, 118.0, 56.0, 41.2. Anal. calcd for $C_{20}H_{12}ClN_3O_3$ (377.78): C, 63.59; H, 3.20; N, 11.12; found: C, 63.40; H, 3.02; N, 11.01%.

*2-Amino-6-chloro-4-(thiophen-2-yl)-4*H*-benzo[*h*]chromene-3-carbonitrile* (**5m**): White powder; IR (KBr) (ν_{max} cm^{-1}): 3445, 3325 (N–H), 2195 (C≡N), 1664 (C=C), 761 (C–S), 802, 761, 705 (aromatic C–H bend); ^{1}H NMR (400 MHz, DMSO-d_6): δ 8.32 (1H, m, ArH), 8.14 (1H, m, ArH), 7.79 (2H, m, ArH), 7.49 (1H, s, ArH), 7.43 (1H, dd, *J* =1.2, 5.2 Hz, ArH), 7.44 (1H, s, ArH), 7.36 (s, NH_2), 7.16 (1H, dd, , *J* = 0.8, 3.6 Hz, ArH), 6.99 (1H, dd, *J* = 3.6, 5.2 Hz, ArH), 5.32 (1H, s,); ^{13}C NMR (100 MHz, DMSO-d_6): δ 160.5, 160.4, 150.6, 142.1, 129.8, 128.8, 128.2, 127.5, 126.3, 126.2, 126.16, 125.4, 124.33 124.3, 121.9, 120.6, 118.8, 56.8. Anal. calcd for $C_{18}H_{11}ClN_2OS$ (338.81): C, 63.81; H, 3.27; N, 8.27; found: C, 63.72; H, 3.11; N, 8.09.

*2-Amino-6-chloro-4-(furan-2-yl)-4*H*-benzo[*h*]chromene-3-car*bonitrile (**5n**): White powder; IR (KBr) (ν_{max} cm^{-1}): 3449, 3330 (N–H), 2186 (C≡N), 1658 (C=C), 1257 (C–O), 857, 758, 734 (aromatic C–H bend); ^{1}H NMR (400 MHz, DMSO-d_6): δ 8.31 (1H, m, ArH), 8.15 (1H, m, ArH), 7.78 (2H, m, ArH), 7.57 (1H, dd, *J* = 1.0, 1.8 Hz, ArH), 7.44 (1H, s, ArH), 7.34 (s, NH_2), 6.41 (1H, dd, *J* = 1.6, 3.2 Hz, ArH), 6.31 (1H, d, *J* = 3.2 Hz, ArH), 5.11 (1H, s); ^{13}C NMR (100 MHz, DMSO-d_6): δ 161.1, 161.1, 156.2, 143.4, 142.9, 129.9, 128.8, 126.1, 124.4, 124.3, 121.8, 120.5, 116.5, 111.0, 107.0, 53.5. Anal. calcd for $C_{18}H_{11}ClN_2O_2$ (322.75): C, 66.99; H, 3.44; N, 8.68; found: C, 66.85; H, 3.31; N, 8.52%.

*3-Amino-8-bromo-2-cyano-1-(4-nitrophenyl)-1*H*-benzo[*f*]chromene* (**6f**): Yellow powder; IR (KBr) (ν_{max} cm^{-1}): 3391, 3325, 3200 (N–H), 2191 (C≡N), 1653 (C=C), 1520, 1346 (NO_2), 1086 (C–Br), 840, 827 (aromatic C–H bend); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.69 (2H, d, *J* = 8.28 Hz, ArH), 7.55 (1H, s, ArH), 7.33 (1H, d, *J* = 8.96 Hz ArH), 7.03 (1H, d, *J* = 8.88 Hz, ArH), 6.96 (1H, d, *J* = 8.96 Hz, ArH), 6.90–6.84 (3H, m, ArH), 4.87 (1H, s, C–H), 4.50 (2H, s, NH_2); ^{13}C NMR (100 MHz, $CDCl_3$): δ 163.1, 159.3, 151.4, 147.8, 147.4, 133.0, 131.3, 131.2, 129.8, 129.4, 128.5, 125.3, 124.9, 119.9, 118.4, 114.2, 60.7, 39.1. Anal. calcd for $C_{20}H_{12}BrN_3O_3$ (422.23): C, 56.89; H, 2.86; N, 9.95; found: C, 56.74; H, 2.75; N, 9.82.

Acknowledgements

The authors are grateful to the Research Council of University of Guilan.

Received 10 November 2016; accepted 9 December 2016
Paper 1604421 doi: 10.3184/174751917X14815427219202
Published online: 22 January 2017

References

1 M. Khafagy, A. El-Wahas, F. Eid and A. El-Agrody, *Il Farmaco*., 2002, **57**, 715.
2 K. Hiramoto, A. Nasuhara, K. Michiloshi, T. Kato and K. Kikugawa, *Mutat. Res*., 1997, **395**, 47.
3 D.R. Anderson, S. Hegde, E. Reinhard, L. Gomez, W.F. Vernier, L. Lee, S. Liu, A. Sambandam, P.A. Snider and L. Masih, *Bioorg. Med. Chem. Lett*., 2005, **15**, 1587.
4 C. Dell and C. Smith, European Patent Appl.: EP537949 *Chem. Abstr*., 1993, **119**, 139102d.
5 G. Bianchi and A. Tava, *Agric. Biol. Chem*., 1987, **51**, 2001.
6 S. Mohr, M. Chirigos, F. Fuhrman and J. Pryor, *Cancer Res*., 1975, **35**, 3750.
7 G. Shanthi, P. T. Perumal, U. Rao and P. K. Sehgal, *Indian J. Chem. B*, 2009, **48**, 1319.
8 T.S. Jin, J.C. Xiao, S.J. Wang and T.S. Li, *Ultrason. Sonochem*., 2004, **11**, 393.
9 T.S. Jin, J.S. Zhang, L.B. Liu, A.Q. Wang and T.S. Li, *Synth. Commun*., 2006, **36**, 2009.
10 D.Q. Shi, S.I. Zhang, Q.Y. Zhuang and X.S. Wang, *Chin. J. Org. Chem*., 2003, **23**, 877.
11 T.S. Jin, J.C. Xiao, S.J. Wang, T.S. Li and X.R. Song, *Synlett*., 2003, **13,** 2001.
12 C. Lu, X.J. Huang, Y.Q. Li, M.Y. Zhou and W. Zheng, *Monatsh. Chem*., 2009, **140**, 45.
13 M.I. Burguete, H. Erytropel, E.G. Verdugo, S.V. Luis and V. Sans, *Green Chem*., 2008, **10**, 401.
14 C. Li, *J. Chem. Rev*., 2005, **105**, 3095.
15 W. Wei, C.J. Li and R.S. Varma, *Clean Tech. Environ. Policy*, 2005, **7**, 62.
16 C.E. Song, *Chem. Commun*., 2004, 1033.
17 J. Dupont, R.F. de Souza and P.A. Suarez, *Chem. Rev*., 2002, **102,** 3667.
18 H. Oliver-Bourbigou and L. Magna, *J. Mol. Catal. A: Chem*., 2002, **419**, 182.
19 A.R. Hajipour and F. Rafiee, *Org. Prep. Proced. Int*., 2010, **42**, 285.
20 R. Sheldon, *Chem. Commun*., 2001, 2399.
21 R. Hagiwara and Y. Ito, *J. Fluorine Chem*., 2000, **105,** 221.
22 T. Welton, *Chem. Rev*., 1999, **99,** 2071.
23 M. Mamaghani, F. Shirini, M. Sheykhan and M. Mohsenimehr, *RSC Adv*., 2015, **5**, 44524.
24 L. Kheirkhah, M. Mamaghani, N.O. Mahmoodi, A. Yahyazadeh, A. Fallah Shojaei and Y. Rostamli, *J. Chin. Chem. Soc*., 2016, **63**, 410.
25 A. Badrian, M. Mamaghani and S. Kamyabi, *Phosphorus Sulfur Silicon*, 2016, **191,** 1375.
26 M. Mamaghani, R. Hossein Nia, F. Shirini, K. Tabatabaeian and M. Rassa. *Med. Chem. Res*., 2015, **24**, 1916.
27 M. Mamaghani, Kh. Tabatabaeian, M. Pourshiva and R. Hossein Nia. *J. Chem. Res*., 2015, **39**, 314.
28 R. Hossein Nia, M. Mamaghani, F. Shirini, Kh. Tabatabaeian and M. Heidary, *Org. Prep. Proc. Int*., 2014, **46**, 152.
29 R. Ballini, G. Bosica and M.L. Conforti, *Tetrahedron*, 2001, **57**, 1395.
30 A. Zhang, M. Zhang and H. Chen, *Synth. Commun*., 2007, **37**, 231.
31 Q.Y. Zhuang, D.Q. Shi and S.J. Tu, *Chin. J. Appl. Chem*., 2002, **19**, 1018.
32 R. Ballini, F. Bigi, M.L. Conforti, D. De Santis, R. Maggi, G. Oppici and G. Sartori, *Catal. Today*, 2000, **60**, 305.
33 K. Gong, H. Wang, D. Fang and Z. Liu, *Catal. Commun*., 2008, **9**, 650.
34 F. Kargar Behbahani and S. Maryam, *J. Korean Chem. Soc*., 2013, **57**, 357.