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Crown ether complex cation ionic liquids (CECILs) as environmentally benign catalysts for three-component synthesis of 4,5-dihydropyrano[3,2-*c*]chromene and 4,5-dihydropyrano[4,3-*b*]pyran derivatives

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Abstract Crown ether complex cation ionic liquids (CECILs) catalyze three-component reaction of aromatic aldehydes, malononitrile, and 4-hydroxycoumarin or 4-hydroxy-6-methylpyrone, in EtOH under reflux, for synthesis of 4,5-dihydropyrano[3,2-*c*]chromene and 4,5-dihydropyrano[4,3-*b*]pyran derivatives. CECILs are environmentally benign, easily obtained, stable catalysts. High conversion, short reaction times, and cleaner reaction profiles are some of the advantages of this method.

Keywords 4,5-Dihydropyrano[3,2-*c*]chromene derivatives · 4,5-Dihydropyrano[4,3-*b*]pyran derivatives · Multicomponent reaction · Crown ether complex cation ionic liquids (CECILs)

Introduction

Compared with other methods, multicomponent reactions (MCRs) have emerged as attractive and powerful strategies for organic synthesis [1–3]. MCRs are highly flexible and enable exceptionally efficient synthesis of complex molecules, frequently with high stereoselectivity, from simple and readily available substrates [4–8]. MCRs have been developed for synthesis of a variety small organic molecules in organic, bioorganic, and medicinal chemistry [9–12] and are regarded

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as vital for synthesis of many important heterocyclic compounds, for example 4,5-dihydropyrano[3,2-*c*]chromene and 4,5-dihydropyrano[4,3-*b*]pyran derivatives.

Dihydropyrano[3,2-*c*]chromenes and their derivatives are of substantial interest because of their wide range of biological properties [13, 14], for example spasmolytic, diuretic, anti-coagulant, anticancer, and anti-anaphylactic activity [15, 16]. 4,5-Dihydropyrano[4,3-*b*]pyran derivatives also have wide range of pharmacological and biological applications, because of their fungicidal, insecticidal, acaricidal [17], antiviral [18], antileishmanial, and anticonvulsant activity [19].

Ionic liquids (ILs), salts with melting points below 100 °C consisting of ions, have attracted much attention from research groups because of their unique properties and novel applications. ILs have low vapor pressure, excellent thermal stability, desirable solvating properties, and are recyclable [20]. They have been used in many organic reactions, for example, hydrogenation, oxidation [21–25], three-component reactions [26], and carbon–carbon bond-forming reactions, for example Michael addition, the Henry reaction, Knoevenagel condensation, and Heck reaction [27]. Crown ether complex ionic liquids (CECILs), have been synthesized by chelating crown ethers with alkali metal cations [27]. Because electrostatic interactions between the large cations and the anions are relatively weak compared with van der Waals forces, the lattice energy and melting points of the crystals are low.

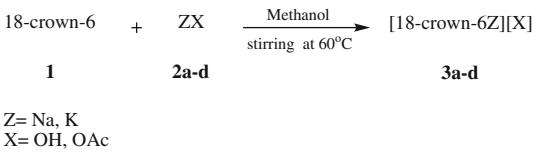
In the work reported herein, we synthesized a series of crown ether complex cation ionic liquids (CECILs), by chelating crown ethers with alkali metal cations, and used them as environmentally benign catalysts for synthesis of 4,5-dihydropyrano[3,2-*c*]chromene and 4,5-dihydropyrano[4,3-*b*]pyran derivatives by three-component reaction of aromatic aldehydes, malononitrile, and 4-hydroxycoumarin or 4-hydroxy-6-methylpyrone, in EtOH, under reflux.

Results and discussion

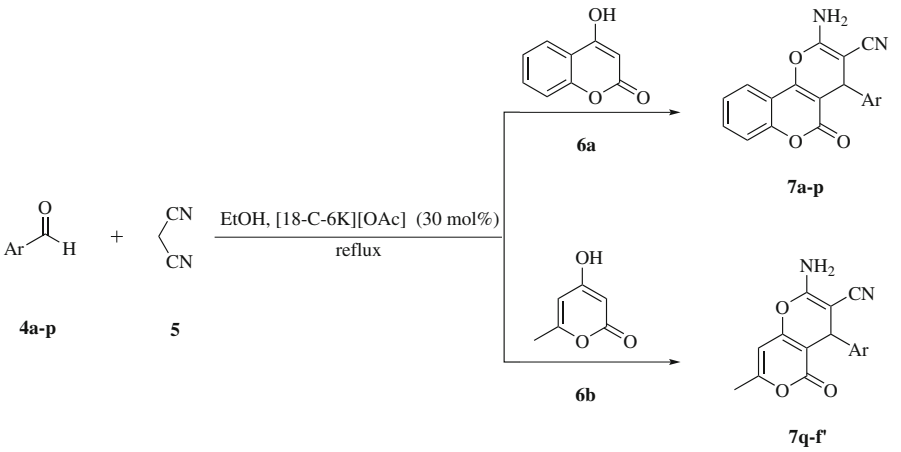
In this work we dissolved the crown ether (**1**) and inorganic or organic base (**2a–d**) in methanol to generate the required CECIL (**3a–d**) (Scheme 1).

We then used the CECILs as catalysts for three-component reaction of aromatic aldehydes (**4a–p**), malononitrile (**5**), and 4-hydroxycoumarin (**6a**) or 4-hydroxy-6-methylpyrone (**6b**) for synthesis of 4,5-dihydropyrano[3,2-*c*]chromene (**7a–p**) and 4,5-dihydropyrano[4,3-*b*]pyran (**7q–f′**) derivatives, in EtOH, under reflux (Scheme 2).

To optimize the reaction conditions, the reaction between benzaldehyde (**4a**), malononitrile (**5**), and 4-hydroxycoumarin (**6a**) was chosen as a model reaction.



Scheme 1 Synthesis of crown ether complex cation ionic liquids (CECILs)



Scheme 2 Three-component reaction of aromatic aldehydes (**4a–p**), malononitrile (**5**) and 4-hydroxycoumarin (**6a**) or 4-hydroxy-6-methylpyrone (**6b**) in the presence of catalytic amounts of [18-C-6 K][OAc]

Table 1 Optimization of the model reaction between benzaldehyde (**4a**), malononitrile (**5**) and 4-hydroxycoumarin (**6a**)

Entry	Solvent	Catalyst	Catalyst (mol%)	Time (min)	Yield (%)
1	EtOH	[18-C-6K][OAc]	30	15	90
2	Ethyl acetate	[18-C-6K][OAc]	30	45	78
3	Acetonitrile	[18-C-6K][OAc]	30	40	80
4	Toluene	[18-C-6K][OAc]	30	80	60
5	EtOH	[18-C-6Na][OAc]	30	20	88
6	EtOH	[18-C-6K][OH]	30	27	85
7	EtOH	[18-C-6Na][OH]	30	30	83
8	EtOH	[18-C-6K][OAc]	10	25	82
9	EtOH	[18-C-6K][OAc]	20	20	88
10	EtOH	[18-C-6K][OAc]	40	15	90

When this three-component reaction was performed in the presence of [18-C-6K][OAc] (30 mol%), in EtOH, under reflux, the 2-amino-5-oxo-4-phenyl-4,5-dihydropyrano[3,2-*c*]chromene-3-carbonitrile **7a** was obtained in 90 % yield within 15 min. This reaction was also carried out in other solvents (ethyl acetate, acetonitrile, and toluene), but the best results in terms of reaction time and yield of the desired product **7a** were obtained when the reaction was conducted in EtOH (Table 1, entries 1–4). Other CECILs were also used as catalysts (Table 1, entries 5–7). We also optimized the quantity of catalysts. The best results were obtained when the reactions were performed in the presence of 30 mol% [18-C-6K][OAc] (Table 1, entries 8–10).

On the basis of these results we decided to use this method for synthesis of 4,5-dihydropyrano[3,2-*c*]chromene (**7a**–**p**) and 4,5-dihydropyrano[4,3-*b*]pyran (**7q**–**f′**) derivatives by three-component reaction of aromatic aldehydes (**4a**–**p**), malononitrile (**5**) and 4-hydroxycoumarin (**6a**) or 4-hydroxy-6-methylpyrone (**6b**), in EtOH, under reflux, in the presence of [18-C-6K][OAc] (30 mol%) (Table 2).

Conclusion

In summary, we report use of crown ether complex cation ionic liquids (CECILs) as catalysts for three-component reaction of aromatic aldehydes, malononitrile, and 4-hydroxycoumarin or 4-hydroxy-6-methylpyrone, for synthesis of 4,5-dihydropyrano[3,2-*c*]chromene and 4,5-dihydropyrano[4,3-*b*]pyran derivatives. These reactions were performed in EtOH under reflux. High yields, operational simplicity, clean reaction conditions are advantages of this procedure that make it a useful practical process for synthesis of these compounds.

Experimental

General Melting points were measured on an Electrothermal-9100 apparatus and are uncorrected. IR spectra were recorded on a Brucker FT-IR Tensor 27 infrared spectrophotometer. ^{1}H NMR spectra were recorded on a Brucker Avance III 400 MHz spectrometer. ^{13}C NMR spectra were recorded on the same instruments at 100 MHz. TMS was used as internal standard for NMR spectroscopy. Elemental analysis was performed with a Heraeus CHN-O-Rapid analyzer.

General procedure for synthesis of CECILs (**3a**–**d**)

Organic or inorganic potassium or sodium base (**2a**–**d**) (2 mol) and 18-crown-6 (**1**) (2 mol) in 15 mL methanol was stirred for 1 h at 60 °C. The methanol was removed under reduced pressure. The residue was dried under vacuum to generate the desired CECIL in 100 % yield. Synthesis of CECILs **3b** and **3d** has been reported elsewhere [27].

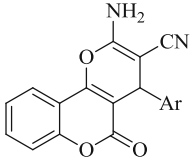
*[18-C-6Na][OH] (**3a**)*

Liquid; ^{1}H NMR (400 MHz, D_2O) δ_{ppm}: 3.92 (s, 24H); ^{13}C NMR (100 MHz, D_2O): δ_{ppm}: 69.01. Anal. calcd. for $C_{12}H_{25}NaO_7$: C, 47.36; H, 8.28 %. Found: C, 47.18; H, 8.12 %.

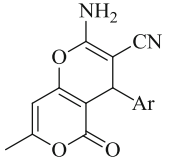
*[18-C-6K][OH] (**3b**)*

White powder; M.P. 38 °C; ^{1}H NMR (400 MHz, D_2O) δ_{ppm}: 3.58 (s, 24H); ^{13}C NMR (100 MHz, D_2O): δ_{ppm}: 68.79. Anal. calcd. for $C_{12}H_{25}KO_7$: C, 44.98; H, 7.86 %. Found: C, 44.80; H, 7.71 %.

Table 2 Three-component reaction of aromatic aldehydes (**4a–p**), malononitrile (**5**) and 4-hydroxycoumarin (**6a**) or 4-hydroxy-6-methylpyrone (**6b**)



7a-p



7q-f'

Compd. no.	Activated C–H acid	Ar	Time (min)	Yield (%)	M.P. observed (°C)	M.P. reported (°C)
7a	**6a**	C_6H_5	15	90	259–261	261–263 [28]
7b	**6a**	4-Cl–C_6H_4	13	91	265–268	265–267 [28]
7c	**6a**	2-Cl–C_6H_4	13	91	265–267	266–268 [29]
7d	**6a**	2,4-$(Cl)_2$–C_6H_3	12	92	253–255	256–258 [30]
7e	**6a**	4-Br–C_6H_4	13	91	246–248	247–250 [30]
7f	**6a**	2-Br–C_6H_4	13	90	293–296	295–297 [29]
7g	**6a**	4-NO_2–C_6H_4	12	92	250–251	250–252 [28]
7h	**6a**	3-NO_2–C_6H_4	13	91	264–266	263–265 [28]
7i	**6a**	2-NO_2–C_6H_4	12	91	256–258	–
7j	**6a**	4-CH_3–C_6H_4	18	88	258–260	257–259 [28]
7k	**6a**	4-CH_3O–C_6H_4	20	87	232–234	235–237 [28]
7l	**6a**	2-CH_3O–C_6H_4	20	88	246–248	247–249 [29]
7m	**6a**	4-OH–C_6H_4	25	85	257–260	258–260 [28]
7n	**6a**	Furan-2-yl	22	89	250–253	253–255 [28]
7o	**6a**	Thiophen-2-yl	23	88	227–229	226–230 [30]
7p	**6a**	Pyridin-3-yl	17	90	257–259	–
7q	**6b**	C_6H_5	18	89	233–235	234–236 [31]

Table 2 continued

Compd. no.	Activated C–H acid	Ar	Time (min)	Yield (%)	M.P. observed (°C)	M.P. reported (°C)
7r	**6b**	4-Cl–C_6H_4	15	90	230–231	231–232 [32]
7s	**6b**	2-Cl–C_6H_4	15	90	269–272	270–271 [32]
7t	**6b**	2,4-$(Cl)_2$–C_6H_3	13	91	233–234	234–235 [32]
7u	**6b**	4-Br–C_6H_4	15	90	220–222	223–225 [32]
7v	**6b**	2-Br–C_6H_4	15	89	271–273	–
7w	**6b**	4-NO_2–C_6H_4	13	91	215–217	215–218 [31]
7x	**6b**	3-NO_2–C_6H_4	15	89	229–232	232–233 [32]
7y	**6b**	2-NO_2–C_6H_4	13	90	261–263	–
7z	**6b**	4-CH_3–C_6H_4	22	87	222–223	224–225 [31]
7a′	**6b**	4-CH_3O–C_6H_4	25	85	202–204	202–205 [31]
7b′	**6b**	2-CH_3O–C_6H_4	25	86	243–245	–
7c′	**6b**	4-OH–C_6H_4	30	85	>300	–
7d′	**6b**	Furan-2-yl	20	88	220–222	223–224 [31]
7e′	**6b**	Thiophen-2-yl	22	87	240–243	242–244 [31]
7f′	**6b**	Pyridin-3-yl	17	89	222–224	–

*[18-C-6Na][OAc] (**3c**)*

White powder; M.P. 56 °C; ^{1}H NMR (400 MHz, D_2O) δ_{ppm}: 3.79 (s, 24H), 1.81 (s, 3H); ^{13}C NMR (100 MHz, D_2O): δ_{ppm}: 179.01, 69.03, 25.12. Anal. calcd. for $C_{14}H_{27}NaO_8$: C, 48.55; H, 7.86 %. Found: C, 48.36; H, 7.70 %.

*[18-C-6K][OAc] (**3d**)*

White powder; M.P. 75 °C; ^{1}H NMR (400 MHz, D_2O) δ_{ppm}: 3.38 (s, 24H), 1.79 (s, 3H); ^{13}C NMR (100 MHz, D_2O): δ_{ppm}: 178.88, 68.26, 24.12. Anal. calcd. for $C_{14}H_{27}KO_8$: C, 46.39; H, 7.51 %. Found: C, 46.20; H, 7.34 %.

Typical procedure for the of 4,5-dihydropyrano[3,2-*c*]chromene (**7a**–**p**) and 4,5-dihydropyrano[4,3-*b*]pyran (**7q**–**f′**) derivatives

A mixture of aromatic aldehyde (**4a**–**p**) (2 mmol), malononitrile (**5**) (2 mmol), and 4-hydroxycoumarin (**6a**) or 4-hydroxy-6-methylpyrone (**6b**) (2 mmol), and [18-C-6K][OAc] (30 mol%) in EtOH (10 mL) was heated under reflux for the time reported in Table 2 (the progress of the reaction being monitored by TLC with hexane–ethyl acetate as mobile phase). After completion of the reaction, the reaction mixture was poured into ice-cold water; the crude product was isolated by filtration, dried, and recrystallized from ethanol.

*2-Amino-4-(2-nitrophenyl)-5-oxo-4,5-dihydropyrano[3,2-c]chromene-3-carbonitrile (**7i**)*

White powder; IR (KBr, ν_{max}/cm^{-1}): 3,392, 3,312 (NH_2), 2,192 (CN), 1,670 (C=O), 1,600, 1,577 (C=C); ^{1}H NMR (400 MHz, DMSO-d_6) δ_{ppm}: 7.89–7.42 (m, 10H, CH–Ar, NH_2), 5.23 (s, 1H, CH); ^{13}C NMR (100 MHz, DMSO-d_6) δ_{ppm}: 161.29 (C=O), 160.22 (C6), 155.20 (C2), 153.75, 150.79, 138.95, 135.26, 134.66, 132.77, 130.04, 126.30, 125.57, 124.15, 120.33, 118.18, 114.38 (CN), 104.85 (C5), 57.73 (C3), 33.22 (C4); Anal. calcd. for $C_{19}H_{11}N_3O_5$: C, 63.16; H, 3.07; N, 11.63 %. Found: C, 62.95; H, 2.91; N, 11.42 %.

*2-Amino-5-oxo-4-(pyridin-3-yl)-4,5-dihydropyrano[3,2-c]chromene-3-carbonitrile (**7p**)*

White powder; IR (KBr, ν_{max}/cm^{-1}): 3,376, 3,280 (NH_2), 2,192 (CN), 1,670 (C=O), 1,603, 1,571 (C=C); ^{1}H NMR (400 MHz, DMSO-d_6) δ_{ppm}: 8.52–7.33 (m, 10H, CH–Ar, NH_2), 4.53 (s, 1H, CH); ^{13}C NMR (100 MHz, DMSO-d_6) δ_{ppm}: 161.16 (C=O), 159.70 (C6), 155.40 (C2), 153.81, 150.64, 149.83, 140.37, 137.13, 134.58, 126.22, 125.43, 124.14, 120.66, 118.13, 114.52 (CN), 104.52 (C5), 58.65 (C3), 36.33 (C4); Anal. calcd. for $C_{18}H_{11}N_3O_3$: C, 68.14; H, 3.49; N, 13.24 %. Found: C, 67.93; H, 3.30; N, 13.05 %.

*2-Amino-4-(2-bromophenyl)-7-methyl-5-oxo-4,5-dihydropyrano[4,3-b]pyran-3-carbonitrile (**7v**)*

Yellow powder; IR (KBr, ν_{max}/cm^{-1}): 3,456, 3,344 (NH_2), 2,192 (CN), 1,664 (C=O), 1,603, 1,574 (C=C); ^1H NMR (400 MHz, DMSO-d_6) δ_{ppm}: 7.54–7.15 (m, 6H, CH–Ar, NH_2), 6.26 (s, 1H, CH), 4.78 (s, 1H, CH), 2.20 (s, 3H, CH_3); ^{13}C NMR (100 MHz, DMSO-d_6) δ_{ppm}: 162.75 (C=O), 160.36 (C6), 159.77 (C2), 143.69, 134.38, 132.18, 130.52, 129.79, 124.47, 120.42, 113.23 (CN), 101.44 (C5), 99.48 (CH), 58.29 (C3), 37.56 (C4), 20.95 (CH_3); Anal. calcd. for $C_{16}H_{11}BrN_2O_3$: C, 53.50; H, 3.09; N, 7.80 %. Found: C, 53.23; H, 2.92; N, 7.62 %.

*2-Amino-7-methyl-4-(2-nitrophenyl)-5-oxo-4,5-dihydropyrano[4,3-b]pyran-3-carbonitrile (**7y**)*

White powder; IR (KBr, ν_{max}/cm^{-1}): 3,472, 3,360 (NH_2), 2,192 (CN), 1,670 (C=O), 1,606, 1,574 (C=C); ^1H NMR (400 MHz, DMSO-d_6) δ_{ppm}: 7.84–7.35 (m, 6H, CH–Ar, NH_2), 6.27 (s, 1H, CH), 5.05 (s, 1H, CH), 2.18 (s, 3H, CH_3); ^{13}C NMR (100 MHz, DMSO-d_6) δ_{ppm}: 163.05 (C=O), 160.36 (C6), 159.90 (C2), 150.85, 139.15, 135.16, 132.55, 129.92, 125.47, 120.41, 114.04 (CN), 101.67 (C5), 99.57 (CH), 57.56 (C3), 32.57 (C4), 20.91 (CH_3); Anal. calcd. for $C_{16}H_{11}N_3O_5$: C, 59.08; H, 3.41; N, 12.92 %. Found: C, 58.89; H, 3.23; N, 12.74 %.

*2-Amino-4-(2-methoxyphenyl)-7-methyl-5-oxo-4,5-dihydropyrano[4,3-b]pyran-3-carbonitrile (**7b′**)*

Yellow powder; IR (KBr, ν_{max}/cm^{-1}): 3,488, 3,344 (NH_2), 2,192 (CN), 1,670 (C=O), 1,600, 1,574 (C=C); ^1H NMR (400 MHz, DMSO-d_6) δ_{ppm}: 7.17–6.84 (m, 6H, CH–Ar, NH_2), 6.22 (s, 1H, CH), 4.48 (s, 1H, CH), 3.69 (s, 3H, OCH_3), 2.18 (s, 3H, CH_3); ^{13}C NMR (100 MHz, DMSO-d_6) δ_{ppm}: 162.97 (C=O), 160.44 (C6), 160.28 (C2), 158.78, 132.60, 130.67, 129.93, 127.25, 122.05, 121.11, 113.34 (CN), 101.64 (C5), 99.48 (CH), 58.29 (C3), 57.29 (OCH_3), 33.26 (C4), 20.89 (CH_3); Anal. calcd. for $C_{14}H_{14}N_2O_4$: C, 65.80; H, 4.55; N, 9.03 %. Found: C, 65.62; H, 4.37; N, 8.84 %.

*2-Amino-4-(4-hydroxyphenyl)-7-methyl-5-oxo-4,5-dihydropyrano[4,3-b]pyran-3-carbonitrile (**7c′**)*

Brown powder; IR (KBr, ν_{max}/cm^{-1}): 3,728–3,024 (broad peak, OH, NH_2), 2,192 (CN), 1,664 (C=O), 1,574, 1,552 (C=C); ^1H NMR (400 MHz, DMSO-d_6) δ_{ppm}: 9.12 (s, 1H, OH), 7.02–6.73 (m, 6H, CH–Ar, NH_2), 6.21 (s, 1H, CH), 4.52 (s, 1H, CH), 2.20 (s, 3H, CH_3); ^{13}C NMR (100 MHz, DMSO-d_6) δ_{ppm}: 162.65 (C=O), 160.36 (C6), 159.74 (C2), 156.43, 132.46, 130.40, 129.16, 126.44, 122.14, 120.21, 113.58 (CN), 101.24 (C5), 99.53 (CH), 58.29 (C3), 37.49 (C4), 20.92 (CH_3); Anal. calcd. for $C_{16}H_{12}N_2O_4$: C, 64.86; H, 4.08; N, 9.46 %. Found: C, 64.68; H, 3.91; N, 9.27 %.

*2-Amino-7-methyl-5-oxo-4-(pyridin-3-yl)-4,5-dihydropyrano[4,3-b]pyran-3-carbonitrile (**7f**)*

Yellow powder; IR (KBr, ν_{max}/cm^{-1}): 3,408, 3,392 (NH_2), 2,192 (CN), 1,664 (C=O), 1,587, 1,523 (C=C); ^1H NMR (400 MHz, DMSO-d_6) δ_{ppm}: 8.43 (s, 2H, NH_2), 7.59–7.28 (m, 4H, CH–Ar), 6.27 (s, 1H, CH), 4.35 (s, 1H, CH), 2.20 (s, 3H, CH_3); ^{13}C NMR (100 MHz, DMSO-d_6) δ_{ppm}: 162.96 (C=O), 160.10 (C6), 159.80 (C2), 150.61, 149.83, 140.52, 136.82, 125.34, 120.75, 113.21 (CN), 101.34 (C5), 99.61 (CH), 58.53 (C3), 35.61 (C4), 20.91 (CH_3); Anal. calcd. for $C_{15}H_{11}N_3O_3$: C, 64.05; H, 3.94; N, 14.94 %. Found: C, 63.88; H, 3.78; N, 14.76 %.

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References

1. J. Zhu, *Multicomponent Reactions* (Wiley-VCH, Weinheim, 2005)
2. L.F. Tietze, Chem. Rev. **96**, 115 (1996)
3. L.F. Tietze, U. Beifuss, Angew. Chem. **105**, 137 (1993)
4. D.A. Horton, G.T. Bourne, M.L. Smythe, Chem. Rev. **103**, 893 (2003)
5. A.S. Al-bogami, Res. Chem. Intermed. (2013). doi:10.1007/s11164-013-1171-7
6. R. Sandaroos, S. Damavandi, Res. Chem. Intermed. **39**, 4167 (2013)
7. M. Abaszadeh, M. Seifi, A. Asadipour, Res. Chem. Intermed. (2014). doi:10.1007/s11164-014-1711-9
8. F. Matloubi Moghaddam, M.R. Khodabakhshi, A. Latifkar, Tetrahedron Lett. **55**, 1251 (2014)
9. B. Ganem, Acc. Chem. Res. **42**, 463 (2009)
10. A. Domling, I. Ugi, Angew. Chem. Int. Ed. **39**, 3169 (2000)
11. A. Shaabani, A. Maleki, A.H. Rezayan, A. Sarvary, Mol. Divers. **15**, 41 (2011)
12. M.G. Dekamin, Z. Mokhtari, Tetrahedron **68**, 922 (2012)
13. G.R. Green, J.M. Evans, A.K. Vong, *In Comprehensive Heterocyclic Chemistry II* (Pergamon: Oxford, 1995; Vol. 5; p 469)
14. C.S. Konkoy, D.B. Fick, S.X. Cai, N.C. Lan, J.F.W. Keana, PCT Int. Appl. WO 0075123, (2000). Chem. Abstr. **134**, 29313a (2001)
15. L.L. Andreani, E. Lapi, Bull. Chim. Farm. **99**,583 (1960)
16. L. Bonsignore, G. Loy, D. Secci, A. Calignano, Eur. J. Med. Chem. **28**, 517 (1993)
17. M. Uher, V. Konecny, O. Rajniakove, Chem. Pap. **48**, 282 (1994)
18. M. Perez-Perez, J. Balzarini, J. Rozenski, E. De-Clercq, P. Herdewijn, Bioorg. Med. Chem. Lett. **5**, 1115 (1995)
19. H. Takao, K. Murai, N. Yasudomi, T. Goto, N. Umetsu, T. Horie, Nippon Noyaku Gakkaishi **19**, 151 (1994)
20. V.M. Sanjay, *Ionic Liquids in Synthesis* (Wiley-VCH, United Kingdom, 2008)
21. S. Li, Y. Lin, H. Xie, S. Zhang, J. Xu, Org. Lett. **8**, 391 (2006)
22. R. Wang, B. Twamley, J.M. Shreeve, J. Org. Chem. **71**, 426 (2006)
23. W. Qian, E. Jin, W. Bao, Y. Zhang, Angew. Chem. **117**, 974 (2005)
24. B.C. Ranu, A. Das, S. Samanta, J. Chem. Soc. Perkin Trans. **1**, 1520 (2002)
25. H. Olivier-Bourbigou, L. Magna, D. Morvan, Appl. Catal. A **373**, 1 (2010)
26. S.D. Jagadalea, M.B. Deshmukh, A.G. Mulikb, D.R. Chandamb, P.P. Patilb, D.R. Patilb, S.A. Sankpal, Der Pharma Chemica **4**, 202 (2012)
27. Y. Song, H. Jing, B. Li, D. Bai, Chem. Eur. J. **17**, 8731 (2011)
28. M.G. Dekamin, M. Eslami, A. Maleki, Tetrahedron **69**, 1074 (2013)
29. H.J. Wang, J. Lu, Z.H. Zhang, Monatsh. Chem. **141**, 1107 (2010)
30. S. Jain, D. Rajguru, B.S. Keshwal, A.D. Acharya, ISRN Org. Chem. **24**, 185120 (2013)
31. D. Rajguru, B.S. Keshwal, S. Jain, Med. Chem. Res. **22**, 5934 (2013)
32. X.S. Wang, J.X. Zhou, Z.S. Zeng, Y.L. Li, D.Q. Shi, S.J. Tua, Arkivoc **xi**, 107 (2006)