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$CeCl_3 \cdot 7H_2O$-Catalyzed One-Pot Kabachnik–Fields Reaction: A Green Protocol for Three-Component Synthesis of α-Aminophosphonates

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ABSTRACT: *$CeCl_3 \cdot 7H_2O$ has been utilized as an efficient Lewis acid catalyst for the three-component coupling of aldehydes, aromatic amines, and diethylphosphite to produce α-aminophosphonates under solvent-free conditions. The advantages of this protocol are high yield, mild reaction conditions, less environmental pollution, and simple work-up procedure.* © 2010 Wiley Periodicals, Inc. Heteroatom Chem 21:397–403, 2010; View this article online at wileyonlinelibrary.com. DOI 10.1002/hc.20635

INTRODUCTION

Phosphonate-containing molecules are biologically potent. Their diverse applications include as inhibitors of synthase [1], HIV protease [2], rennin [3], PTPases [4–6], antibiotics [5], enzymes [6], UDP-galactopyranose mutase [6a], and herbicides [7] and as surrogates of α-amino acids [8]. α-Aminophosphonates have attracted attention as substrates in the synthesis of phosphonopeptides (peptido mimetics) [9]. However, there are also a few reports available in which antitumor activity of α-aminophosphonates has been investigated [10].

Generally, α-aminophosphonates are prepared by the addition of phosphorous nucleophiles to imines in the presence of acids [11]. Recently, three-component synthesis starting from aldehydes, amines, and diethylphosphite or triethylphosphite has been reported by using Lewis and Brønsted acid catalysts such as $LiClO_4$ [12], $InCl_3$ [13a], $FeCl_3$ [13b], $ZrCl_4$ [13c], $ZrOCl_2 \cdot 8H_2O$ [13d], lanthanide triflates/magnesium sulfate [14], $SbCl_3/Al_2O_3$ [15a], $TaCl_5$-SiO_2 [15b], $BiNO_3 \cdot 5H_2O$ [15c], amberlyst-15 [16a], montmorillonite clay-MW [16b], silica sulfuric acid [16c], sulfamic acid [16d], Al_2O_3-MW [17a], TiO_2 [17b], CF_3CO_2H [18], $Sc(DS)_3$ [19a], β-cyclodextrine [19b], SDS [19c], $BF_3 \cdot Et_2O$ [20], $M(OTf)_n$ [21], $M(ClO_4)_n$ [22], in an ionic liquid [23] and under thermal conditions [24]. By considering the importance of α-aminophosphonates as biologically active compounds, there is a great demand for the development of more convenient and practically efficient methods for the synthesis of α-aminophosphonates.

Cerium(III) chloride heptahydrate [25] ($CeCl_3 \cdot 7H_2O$) has emerged as a potential catalyst in affecting various organic transformations due to its high catalytic ability, water tolerance, being a "friendly" reagent, economic viability, and easy availability. To our knowledge, no Kabachnik–Fields reaction catalyzed by $CeCl_3 \cdot 7H_2O$ has been reported. In this paper, as a part of our ongoing green organic chemistry program [26], we wish to report an efficient and versatile procedure for

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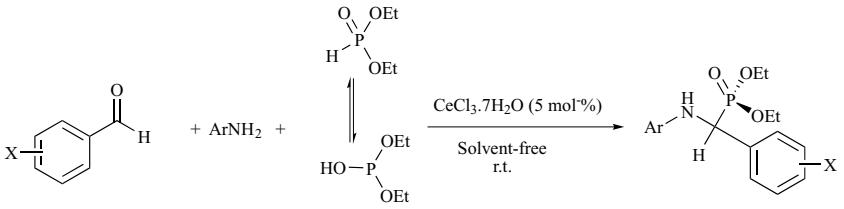
Contract grant sponsor: Research Council of Yazd University.



SCHEME 1

affecting the one-pot, three-component reaction of an aldehyde, an amine, and diethylphosphite for the preparation of α-aminophosphonates in the presence of catalytic amounts of the $CeCl_3{\cdot}7H_2O$ under solvent-free conditions (Scheme 1).

RESULTS AND DISCUSSION

At the outset, the three-component reaction of benzaldehyde, aniline, and diethylphosphite was investigated in various conditions at room temperature (Table 1). To optimize the reaction conditions, the model reaction was examined under solvent-free conditions and in solvents such as CH_3CN, acetone, CH_2Cl_2, and EtOH in the presence of cerium salts. The best reaction condition resulted when the molar ratio of benzaldehyde (2 mmol)/aniline (2 mmol)/diethylphosphate (2.2 mmol)/$CeCl_3{\cdot}7H_2O$ (5 mol%) was used at room temperature under solvent-free conditions. In these conditions, the reaction proceeded well and was completed after 5 h to produce the desired diethyl phenyl(phenylamino)methylphosphonate in 95% isolated yield. To show the merit of the catalyst, a similar reaction in the absence of $CeCl_3{\cdot}7H_2O$ catalyst was studied (Table 1, entry 1). The reaction did not proceed even after 24 h.

TABLE 1 Optimization of Reaction Conditions[a]

Entry	*Solvent*	*Catalyst (mol%)*	*Time (h)*	*Yield (%)*
1	CH_3CN	–	24	<10
2	CH_3CN	$Ce(NO_3)_3$	24	70
3	CH_3CN	$(NH_4)Ce(NO_3)_6$	14	94
4	CH_3CN	$CeCl_3{\cdot}7H_2O$ (5)	12	93
5	CH_3CN	$CeCl_3{\cdot}7H_2O$ + NaI (5)	12	95
6	CH_3CN	$CeCl_3{\cdot}7H_2O$ + NaI/Al_2O_3 (5)	24	80
7	Acetone	$CeCl_3{\cdot}7H_2O$ (5)	10	94
8	CH_2Cl_2	$CeCl_3{\cdot}7H_2O$ (5)	24	70
9	Ethanol	$CeCl_3{\cdot}7H_2O$ (5)	24	70
10	Solvent-free	$CeCl_3{\cdot}7H_2O$ (5)	5	95
11	Solvent-free	$CeCl_3{\cdot}7H_2O$ (2.5)	8	92

[a]Reaction conditions: solvent (0.5 mL), room temperature, benzaldehyde (2 mmol), aniline (2 mmol), and diethylphosphate (2.2 mmol).

Then, to show the general application of the method [25], several aldehydes, amines, and diethylphosphate with similar molar ratios as mentioned earlier were reacted smoothly in appropriate reaction times (2.5–24 h) to yield the corresponding α-aminophosphonates in high to excellent isolated yields (87–95%). The examples studied covered electron-rich and electron- deficient aromatic aldehydes with aniline derivatives containing strong electron-donating and electron-withdrawing groups and also show that cyclohexanone as a ketone reacts smoothly to give the corresponding α-aminophosphonate. The results of this study are summarized in Table 2.

A reasonable pathway for the reaction of an aldehyde with an amine and diethylphosphite conducted in the presence of $CeCl_3{\cdot}7H_2O$ is presented in Fig. 1. The reaction proceeds via formation of imine that undergoes addition with diethylphosphite to afford α-aminophosphonates. $CeCl_3{\cdot}7H_2O$ shows dual activity: One action is to activate the in situ generated imine, and its second function is to bring diethylphosphite molecule close to the imine by the template effect.

Finally, the efficacy of $CeCl_3{\cdot}7H_2O$ was compared with that of other catalysts reported earlier

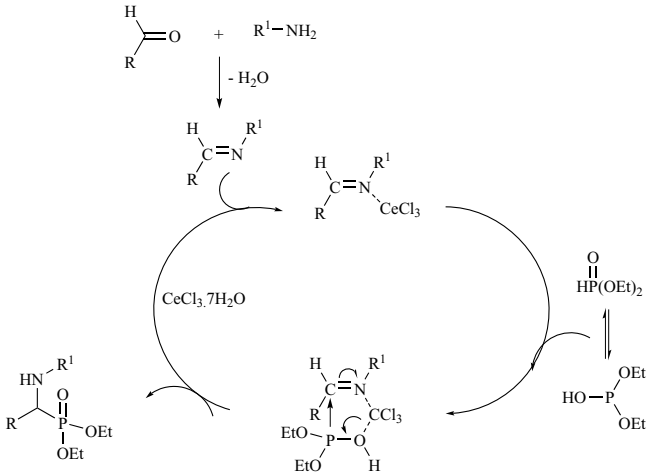
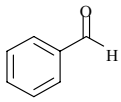
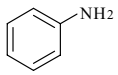
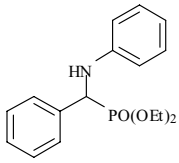
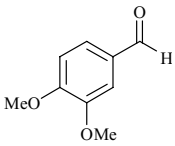
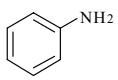
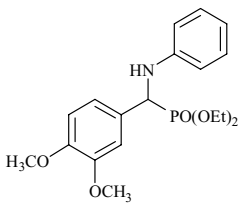
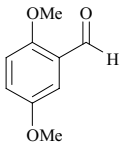
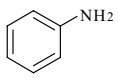
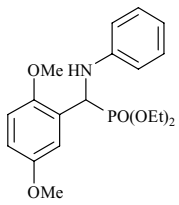
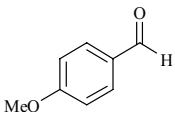
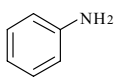
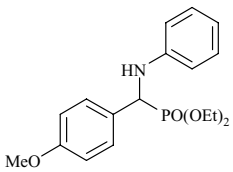
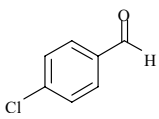
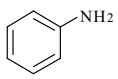
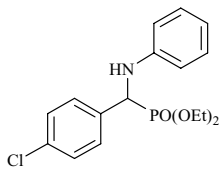
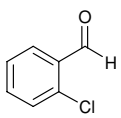
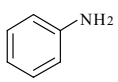
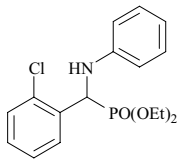
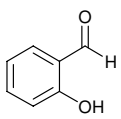
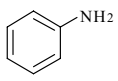
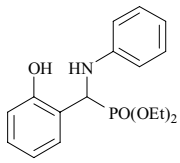
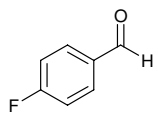
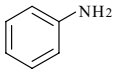
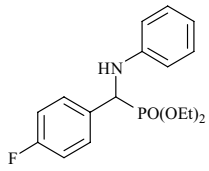


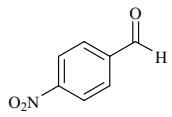
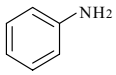
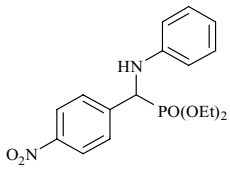
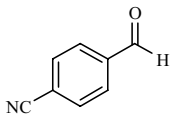
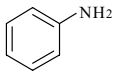
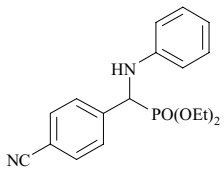
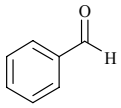
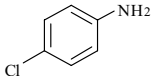
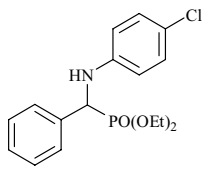
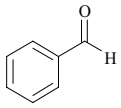
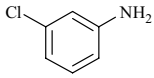
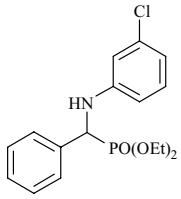
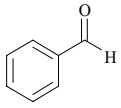
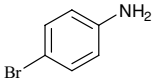
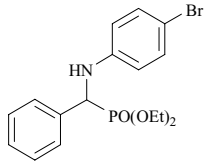
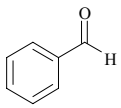
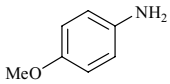
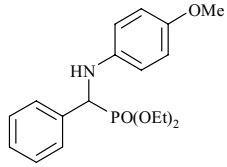
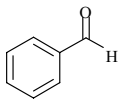
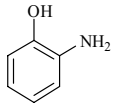
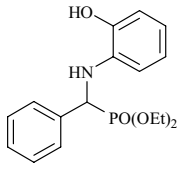
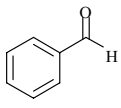
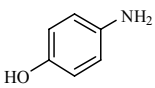
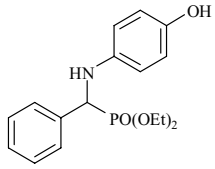
FIGURE 1 A plausible mechanism for the CeCl3·$7H_2O$ catalyzed three-component reaction for the preparation of α-aminophosphonates.

TABLE 2 One-Pot Synthesis of α-Aminophosphonates Catalyzed by $CeCl_3 \cdot 7H_2O$ at Room Temperature under Solvent-Free Conditions[a]

Entry	*Aldehyde*	*Amine*	*Product*[b]	*Time (h)*	*Yield (%)*	*mp Found (Reported)*	*Reference*
1				5	95	87 (86)	[17b]
2				2.5	94	77	–
3				5	92	120	–
4				4.5	91	108	[12]
5				9	90	57 (57)	[17b]
6				14	88	89 (88)	[17b]
7				8	94	91	[15b]
8				20 (9)[c]	94 (95)[c]	79	[23]

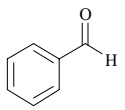
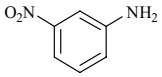
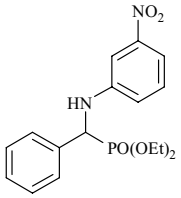
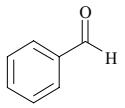
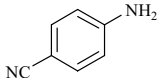
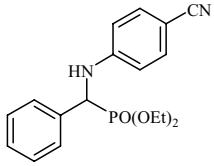
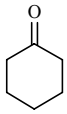
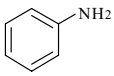
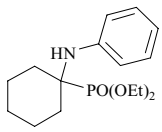
(Continued)

TABLE 2 Continued

Entry	*Aldehyde*	*Amine*	*Product*[b]	*Time (h)*	*Yield (%)*	*mp Found (Reported)*	*Reference*
10				13	90	120 (120)	[17b]
11				10.5	89	105	[15c]
12				9	93	119	[23]
13				5	95	129	[17b]
14				8	92	122	–
15				5	92	115	[15b]
17				10	90	120	[17b]
18				8	93	127	[17b]

(Continued)

TABLE 2 Continued

Entry	*Aldehyde*	*Amine*	*Product*[b]	*Time (h)*	*Yield (%)*	*mp Found (Reported)*	*Reference*
19				8	90	118	[13a]
20				24	89	130	–
21				6	87	108 (104)	[17b]

[a]The ratio of aldehyde (2 mmol), amine (2 mmol), and diethylphosphate (2.2 mmol).
[b]Products were confirmed by physical and spectroscopic methods such as mp, IR, and NMR.
[c]10 mol% $CeCl_3 \cdot 7H_2O$ was used.

TABLE 3 Comparison of the Reaction of Benzaldehyde, Aniline, Diethylphosphate Catalyzed by $CeCl_3 \cdot 7H_2O$ with the Other Catalysts Recently Used for This Reaction

Entry	*Catalyst (mol%)*	*Solvent*	*Temperature (°C)*	*Time (h)*	*Yield (%)*	*References*
1	CF_3CO_2H (25)	–	r.t.	24	96	[18]
2	$ZrCl_4$ (10)	CH_3CN	r.t.	4.5	92	[13c]
3	$InCl_3$ (10)	THF	r.t.	11	93	[13a]
4	TiO_2 (20)	–	50	2.5	98	[17a]
5	[bmim]BF_6 (1 mL)	–	r.t.	8	84	[23]
6	$Bi(NO_3)_3 \cdot 5H_2O$ (10)	–	r.t.	10	93	[15c]
7	$SbCl_3$/ Al_2O_3 (5)	CH_3CN	r.t.	3	91	[15a]
8	$TaCl_5$-SiO_2 (10)	CH_2Cl_2	r.t.	20	90	[15b]
9	–	–	80	0.5	92	[24a]
10	–	–	r.t.	24	N.R.	[23], [16d]
11	$CeCl_3 \cdot 7H_2O$ (5)	–	r.t.	5	95	This work

r.t., room temperature; N.R., no reaction.

in the synthesis of α-aminophosphonates. The data summarized in Table 3 clearly demonstrate the superiority of $CeCl_3 \cdot 7H_2O$ in terms of time, cost, as well as operational simplicity of the reaction.

CONCLUSION

In conclusion, the results reported here show that $CeCl_3 \cdot 7H_2O$ efficiently catalyzes the one-pot synthesis of biologically active α-aminophosphonates in excellent yields via a three-component coupling reaction of aldehydes, amines, and diethylphosphite at room temperature. This protocol has advantages of mild reaction conditions, no environmental pollution, avoiding use of any harmful organic solvent in reaction media and/or in work-up procedure, use of an inexpensive, water-tolerant, and environment-friendly catalyst, and simple work-up procedure.

EXPERIMENTAL

General Remarks

Merck and Fluka chemicals were purchased from Kimia Exir Chemical Co., Tehran, Iran. All the products are known and were characterized by

comparison of their physical data with those reported in the literature. IR spectra were run on a Shimadzu model 8300 FT-IR spectrophotometer. NMR spectra were recorded on a Bruker Avance DPX-250 or 500 MHz. The purity of the products and the progress of the reactions were accomplished by thin-layer chromatography (TLC) on silica-gel polygram SILG/UV_{254} plates.

General Procedure for Preparation of α-Aminophosphonates

To a mixture of aldehyde (2 mmol), amine (2 mmol), and diethyl phosphite (2.2 mmol), $CeCl_3{\cdot}7H_2O$ (0.02 g, 5 mol%) was added and stirred at room temperature for the appropriate reaction time (Table 2). After completion of the reaction (TLC), the mixture was dissolved in hot EtOH (2 mL) and the product was precipitated by adding ice water. The pure α-aminophosphonates were collected with a simple filtration and consequently washed with water (Table 2).

Selected Spectral Data for New Compounds

[(3, 4 - Dimethoxy-phenyl) - phenylamino - methyl] - phosphonic acid diethyl ester (Table 2, entry 2): white solid, mp 77–78°C; ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 7.12$ (dd, $J_1 = 8.4$, $J_2 = 7.5$, 2H), 7.05–7.02 (m, 2H), 6.84 (d, $J = 7.9$, 1H), 6.71 (t, $J = 7.5$, 1H), 6.63 (d, $J = 8.1$,2H), 4.85 (b, 1H, NH), 4.72 (d, $J = 23.8$, 1H), 4.16–4.10 (m, 2H), 3.99–3.95 (m, 1H), 3.88 (s, 3H), 3.86 (s, 3H), 3.75–3.70 (m, 1H), 1.30 (t, $J = 7.1$, 3H), 1.16 (t, $J = 7.1$, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): $\delta = 149.5$, 149.1, 146.9, 129.6, 128.6, 120.6, 118.8, 114.3, 111.5, 111.3, 63.6 (d, $J = 6.9$), 63.6 (d, $J = 6.9$), 56.3, 56.2, 56.2 (d, $J = 151.0$), 16.8 (d, $J = 5.6$, CH_3), 16.7 (d, $J = 5.6$, CH_3); IR = 3284, 2995, 1602, 1515, 1498, 1230, 1020 cm^{-1}; $C_{19}H_{26}NO_5P$ (379): calcd C 60.15, H 6.91; found C 60.03, H 6.90. [(2,5-Dimethoxy-phenyl)-phenylamino-methyl]-phosphonic acid diethyl ester (Table 2, entry 3): white solid, mp 120–121°C; ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.16–7.12 (m, 3H), 6.86 (d, $J = 8.9$, 1H), 6.8 (dt, $J_1 = 8.9$, $J_2 = 2.4$, 1H), 6.73–6.70 (m, 3H), 5.47 (d, $J = 25.1$, 1H), 5.1 (b, 1H, NH), 4.28–4.24 (m, 2H), 3.99–3.97 (m, 1H), 3.93 (s, 3H), 3.76 (s, 3H), 3.74–3.68 (m, 1H), 1.34 (t, $J = 7.1$, 3H), 1.10 (t, $J = 7.1$, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): $\delta = 154.4$, 151.9, 146.7, 146.6, 129.5, 125.6, 118.7, 114.8, 114.2, 114.1, 112.1, 64.2, 56.8, 56.2, 48.5 (d, $J = 155.1$), 16.8 (d, $J = 6.0$), 16.5 (d, $J = 6.0$); IR = 3304, 2984, 2832, 1604, 1500, 1232, 1026 cm^{-1}; $C_{19}H_{26}NO_5P$ (379): calcd C 60.15, H 6.91; found C 60.08, H 6.88. Diethyl (4-bromophenylamino)(phenyl)methylphosphonate (Table 2, entry 14): white solid, mp 122°C; ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 7.47$ (d, $J = 7.2$, 2H), 7.37 (d, $J = 7.2$, 2H), 7.31 (t, $J = 7.2$, 1H), 7.20 (d, $J = 8.5$, 2H), 6.50 (d, $J = 8.5$, 2H), 4.92 (b, 1H, NH), 4.74 (d, $J = 23.2$, 1H), 4.31–4.28 (m, 2H), 3.99–3.97 (m, 1H), 3.69–3.70 (m, 1H), 1.32 (t, $J = 7.0$, 3H), 1.14 (t, $J = 7.0$, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$): $\delta = 145.7$, 135.8, 132.3, 129.1, 128.5, 128.2, 115.9, 110.6, 63.9, 63.7, 56.6 (d, $J = 150.5$), 16.8, 16.6 ppm; IR (KBr): $\tilde{\nu} = 3388$, 2983,1615, 1516, 1235 cm^{-1}; $C_{17}H_{21}BrNO_3P$ (398): calcd C 51.27, H 5.32; found C 51.24, H 5.30. [(4-Cyano-phenylamino)-phenylmethyl]-phosphonic acid diethyl ester (Table 2, entry 20): white solid, mp 130–131°C; ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 7.49$ (d, $J = 7.5$, 2H), 7.39–7.31(m, 5H), 6.64 (d, $J = 8.6$, 2H), 5.78 (b, 1H, NH), 4.80 (d, $J = 24.1$, 1H), 4.19–4.12 (m, 2H), 3.97–3.92 (m, 1H), 3.69–3.64 (m, 1H), 1.33 (t, $J = 7.0$, 3H), 1.13 (t, $J = 7.0$, 3H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$): $\delta = 150.3$, 125.2, 134, 129.2, 128.8, 128.2, 120.5, 113.9, 100.5, 64.1 (d, $J = 6.9$), 63.7 (d, $J = 6.9$), 56.4 (d, $J = 150.5$), 16.8 (d, $J = 5.6$), 16.5 (d, $J = 5.6$) ppm; IR (KBr): $\tilde{\nu} = 3306$, 2986, 2211, 1604, 1527, 1233, 1026 cm^{-1}; $C_{18}H_{21}N_2O_3P$ (344): calcd C 62.78, H 6.15; found C 62.68, H 6.12.

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REFERENCES

[1] Sikosrki, J. A.; Miller, M. J.; Braccolino, D. S.; Cleary, D. G.; Corey, S. D.; Ream, J. E.; Schnur, D.; Shah, A.; Walker, M. C. Phosphorus Sulfur Silicon 1993, 76, 375–378.
[2] Stowasser, B.; Budt, K. H.; Jian-Qi, L.; Peyman, A.; Ruppert, D. Tetrahedron Lett 1992, 33, 6625–6628.
[3] Patel, D. V.; Rielly-Gauvin, K.; Ryono, D. E. Tetrahedron Lett 1990, 31, 5587–5591.
[4] (a) Bruke, T. R., Jr.; George, C.; Wolf, G.; Shoelson, S. E.; Yan, X. J Med Chem 1995, 38, 1386–1396; (b) Bruke, T. R., Jr.; Kole, H. K.; Roller, P. P. Biochem Biophys Res Commun 1994, 204, 129–134.
[5] Atherton, F. R.; Hassall, C. H.; Lambert, R. W. J Med Chem 1986, 29, 29–40.
[6] Peyman, A.; Budt, K. H.; Paning, J. S.; Stowasser, B.; Ruppert, D. Tetrahedron Lett 1992, 33, 4549–4552.
[7] Kafarski, P.; Lejczak, B.; Mastalerz, P. Chem Abstr 1985, 103, 174532.
[8] Yager, K. M.; Taylor, C. M.; Smith, A. B. J Am Chem Soc 1994, 116, 9377–9380.
[9] (a) Giannousis, P. P.; Bartlett, P. A. J Med Chem 1987, 30, 1603–1609; (b) Gancarz, R.; Wieczorek, J. S.

Synthesis 1977, 625–630; (c) Baylis, E. K.; Campbell, C. D.; Dingwall, J. G. J Chem Soc, Perkin Trans 1 1984, 2845–2853; (d) Hilderbrand, R. L. The Role of Phosphonates in Living Systems; CRC Press: Boca Raton, FL, 1982; (e) Kafarski, P.; Lejczak, B. Phosphorus Sulfur Silicon 1991, 63, 193–215.

[10] (a) Pan, W.; Ansiaux, C.; Vincent, S. P. Tetrahedron Lett 2007, 48, 4353–4356; (b) Jin, L. H.; Song, B. A.; Zhang, G. P.; Xu, R. Q.; Zhang, S. M.; Gao, X. W.; Hu, D. Y.; Song Yang, S. Bioorg Med Chem Lett 2006, 16, 1537–1543; (c) Kafarski, P.; Lejczak, B. Current Med Chem 2001, 1, 301–312.

[11] (a) Laschat, S.; Kunz, H. Synthesis 1992, 90–95; (b) Kudzin, Z. H.; Lyzwa, P.; Luczak, J.; Andrijewski, G. Synthesis 1997, 44–47; (c) Lee, S.-G.; Park, J. H.; Kang, J.; Lee, J. K. Chem Commun 2001, 1698–1699.

[12] Saidi, M. R.; Azizi, N. Synlett 2002, 1347–1349.

[13] (a) Ranu, B. C.; Hajra, A.; Jana, U.; Org Lett 1999, 1, 1141–1143; (b) Rezaei, Z.; Firouzabadi, H.; Iranpoor, N., Ghaderi, A., Jafari, M. R., Jafari, A. A.; Zare, H. R. Eur J Med Chem 2009, 44, 4266–4275; (c) Yadav, J. S.; Reddy, S. V. B.; Sarita Raj, K.; Bhaskar Reddy, K.; Prasad, R. A.; Synthesis 2001, 15, 2277–2280; (d) Bhagat, S.; Chakraborti, A. K. J Org Chem 2008, 73, 6029–6032.

[14] Qian, C.; Huang, T. J Org Chem 1998, 63, 4125–4128.

[15] (a) Ambica, S.; Kumar, S. C.; Taneja, M. S.; Hundal, K.; Kapoor, K. Tetrahedron Lett 2008, 49, 2208–2212; (b) Chandrasekhar, S.; Prakash, S. J.; Jagadeshwar, V.; Narsihmulu, Ch. Tetrahedron Lett 2001, 42, 5561–5563; (c) Bhattacharya, A. K.; Kaur, T. Synlett 2007, 745–748.

[16] (a) Tajbakhsh, M.; Heydari, A.; Alinezhad, H.; Ghanei, M.; Khaksar, S. Synthesis 2008, 352–354; (b) Yadav, J. S.; Reddy, B. V. S.; Madan, Ch. Synlett 2001, 1131–1133; (c) Maghsoodlou, M. T.; Habibi Khorassani, S. M.; Hazeri, N.; Rostamizadeh, M.; Sajadikhah, S. S.; Shahkarami, Z.; Maleki, N. Heteroatom Chem 2009, 20, 316–318; (d) Mitragotri, S. D.; Pore, D. M.; Desai, U. V.; Wadgaonkar, P. P. Catal Commun 2008, 9, 1822–1826.

[17] (a) Kaboudin, B.; Nazari, R. Tetrahedron Lett 2001, 42, 8211–8213; (b) Hosseini-sarvari, M. Tetrahedron 2008, 64, 5459–5466.

[18] Akiyama, T.; Sanada, M.; Fuchibe, K. Synlett 2003, 1463–1464.

[19] (a) Manabe, K.; Kobayashi, Sh. Chem Commun 2000, 669–670; (b) Kaboudin, B.; Sorbiunm, M. Tetrahedron Lett 2007, 48, 9015–9017; (c) Sobhani, S.; Vafaee, A. Synthesis 2009, 1909–1915.

[20] Ha, H.-J.; Nam, G.-S. Synth Commun 1992, 22, 1143–1148.

[21] (a) Firouzabadi, H.; Iranpoor, N.; Sobhani, S. Synthesis, 2004, 2692–2696; (b) Sobhani, S.; Tashrifi, Z. Synthetic Commun 2009, 39, 120–131.

[22] Bhagat, S.; Chakraborti, A. K. J Org Chem 2007, 72, 1263–1270.

[23] Yadav, S. J.; Reddy, S. V.; Sreedhar, R. Green Chem 2002, 4, 436–438.

[24] (a) Ranu, B. C.; Hajra, A. Green Chem 2002, 4, 551–554; (b) Hosseini-Sarvari, M. J Iran Chem Soc 2008, 5, 118–124.

[25] (a) Bartoli, G.; Marcantoni, E.; Sambri, L. Synlett 2003, 2101–2116, and references cited therein; (b) Bartoli, G.; Bartolacci, M.; Giuliani, A.; Marcantoni, E.; Massaccesi, M.; Torregiani, E. J Org Chem 2005, 70, 169–174; (c) Yadav, J. S.; Subba Reddy, B. V.; Narayana Kumar, G. G. K. S.; Madhusudhan Reddy, G. Tetrahedron Lett 2007, 48, 4903–4906; (d) Yadav, L. D. S.; Rai V. K. Tetrahedron Lett 2008, 49, 5553–5556.

[26] (a) Jafari, A. A.; Moradgholi, F.; Tamaddon F. Eur J Org Chem 2009, 1249–1255; (b) Jafari, A. A.; Moradgholi, F.; Tamaddon F. J Iran Chem Soc 2009, 6, 588–593; (c) Jafari, A. A.; Moradgholi, F. Acta Chim Slov 2009, 56, 744–748; (d) Firouzabadi, H.; Iranpoor, N.; Jafari, A. A. Adv Synth Catal 2005, 347, 655–661; (e) Firouzabadi, H.; Iranpoor, N.; Jafari, A. A. Adv Synth Catal 2006, 348, 434–438; (f) Tamaddon, F.; Razmi, Z.; Jafari, A. A. Tetrahedron Lett 2010, 51, 1187–1189.