DOI: 10.1002/adsc.201300590

Iron(III)-Catalyzed Synthesis of 1,2,4-Trisubstituted Imidazoles through the Reactions of Amidines and Aldehydes in Air

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Received: July 3, 2013; Revised: July 21, 2013; Published online: ■■ ■■, 0000

Supporting information for this article is available on the WWW under http://dx.doi.org/10.1002/adsc.201300590.

Abstract: A novel and efficient iron(III)-catalyzed synthesis of 1,2,4-trisubstituted imidazoles through the reactions of amidines and aldehydes in air has been developed. Five hydrogen dissociations involving C–H and N–H bond activation are realized under mild conditions in this approach. The procedure is sustainable, simple and environmentally friendly.

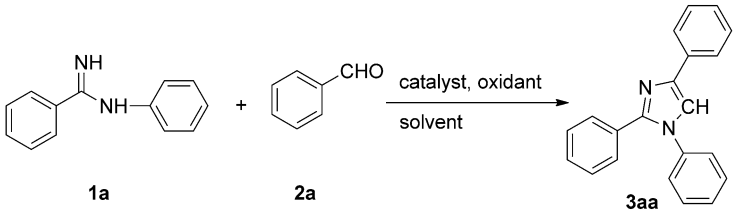
Keywords: aldehydes; amidines; green chemistry; imidazoles; iron

1,2,4-Trisubstituted imidazoles are one of the most important classes of *N*-containing heterocyclic compounds, they have been found in a lot of biologically active drugs[1] and functional materials.[2] In addition, they are of interest in the synthesis of organic semiconductors,[3] dyes,[4] dehydroannulenes,[5] and electroluminescent materials.[6] During the last decades, many methodologies have been developed for the synthesis of multi-substituted imidazoles. Among them, the general one is the reaction of an α-hydroxy ketone/1,2-diketone, a primary amine, an aldehyde and ammonium acetate in one-pot.[7] A number of catalysts for this process have been reported,[8] such as silica gel/$NaHSO_4$, molecular iodine, $HClO_4{\cdot}SiO_2$, $BF_3{\cdot}SiO_2$, hetero-polyacids, Wells–Dawson acid, L-proline, $FeCl_3{\cdot}6H_2O$. Very recently, another way to synthesize multi-substituted imidazoles through the functionalization of C–H/N–H bonds directly was developed. For example, Yan and co-workers[9] reported the copper-catalyzed synthesis of imidazo[1,2-*a*] pyridines *via* oxidative activation of C–H and N–H bonds from aminopyridines and nitroolefins. Neuville and co-workers[10] developed an efficient copper-catalyzed synthesis of 1,2,4-trisubstituted imidazoles using amidines and terminal alkynes. Despite the advances of these methods for multisubstituted imidazoles, most of them require strong bases, long reaction times and an oxygen atmosphere, but only provide low yields. Therefore, the development of improved ways for the synthesis of multi-substituted imidazoles continues to be a challenging goal.

Amidines, as easily available and versatile structures, play an important role as precursors for the synthesis of *N*-containing heterocyclic compounds such as quinazolines, benzimidazoles, pyrimidines or imidazoles.[11] Earlier in this year, our group reported a novel and efficient strategy for the synthesis of tri- or tetrasubstituted imidazoles *via* copper-catalyzed [3+2] cycloaddition reactions of nitroolefins with amidines.[12] As a part of our current studies on the development of new routes in multisubstituted imidazoles synthesis, herein, we first present a new and efficient iron(III)-catalyzed synthesis of 1,2,4-trisubstituted imidazoles *via* oxidative activation of C–H and N–H bonds from amidines and aldehydes.

First, the reaction conditions were optimized using *N*-phenylbenzamidine **1a** and benzaldehyde **2a** as model substrates. As shown in Table 1, the reaction was carried out with *N*-phenylbenzamidine **1a** (0.24 mmol), benzaldehyde **2a** (0.20 mmol) in the presence of $FeCl_3$ (10% mmol) in CH_3NO_2 (2 mL) at 90 °C under an atmosphere of O_2 for 8 h. The desired product **3aa** was obtained in only 5% yield (Table 1, entry 1). When the reactions were carried out in different solvents including THF, DMF and DMSO, they did not give the expected product **3aa** (entries 2–4). The yield of **3aa** was increased to 42% by using a mixture of DMF and CH_3NO_2 as solvent (entry 5). Then, the cyclization reactions were conducted in different solvent mixtures, such as CH_3NO_2/DMSO, CH_3NO_2/toluene, CH_3NO_2/DMA and CH_3NO_2/1,4-dioxane, and the reactions did not provide higher yields (entries 6–9). Based on the above-studied results, we

Table 1. Optimization of the reaction conditions.[a]



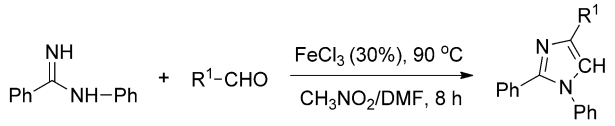
Entry	Catalyst	Oxidant	Solvent	Yield[b]
1	$FeCl_3$ (10%)	O_2	CH_3NO_2	5%
2	$FeCl_3$ (10%)	O_2	THF	0%
3	$FeCl_3$ (10%)	O_2	DMF	0%
4	$FeCl_3$ (10%)	O_2	DMSO	0%
5	$FeCl_3$ (10%)	O_2	CH_3NO_2/DMF	42%
6	$FeCl_3$ (10%)	O_2	CH_3NO_2/DMSO	40%
7	$FeCl_3$ (10%)	O_2	CH_3NO_2/DMA	12%
8	$FeCl_3$ (10%)	O_2	CH_3NO_2/toluene	trace
9	$FeCl_3$ (10%)	O_2	CH_3NO_2/dioxane	trace
10	$FeCl_3$ (10%)	TBHP	CH_3NO_2/DMF	12%
11	$FeCl_3$ (10%)	DDQ	CH_3NO_2/DMF	trace
12	$FeCl_3$ (10%)	Ag_2CO_3	CH_3NO_2/DMF	5%
13	$FeCl_3$ (10%)	*t*-BuOOBu-*t*	CH_3NO_2/DMF	trace
14	$FeCl_3$ (10%)	BPO	CH_3NO_2/DMF	4%
15	$FeCl_3$ (30%)	$CO(NH_2)_2{\cdot}H_2O_2$	CH_3NO_2/DMF	55%
16	$FeCl_3$ (10%)	air	CH_3NO_2/DMF	42%
17	$FeCl_3$ (20%)	air	CH_3NO_2/DMF	45%
18	**$FeCl_3$ (30%)**	**air**	**CH_3NO_2/DMF**	**62%**
19	$FeCl_3$ (50%)	air	CH_3NO_2/DMF	54%
20	$FeBr_3$ (30%)	air	CH_3NO_2/DMF	55%
21	$Fe(OTf)_3$ (30%)	air	CH_3NO_2/DMF	45%
22	$Fe(acac)_3$ (30%)	air	CH_3NO_2/DMF	12%
23	CuI (30%)	air	CH_3NO_2/DMF	0%
24[c]	$FeCl_3$ (30%)	air	CH_3NO_2/DMF	44%
25[d]	$FeCl_3$ (30%)	air	CH_3NO_2/DMF	62%

[a] *Reaction conditions:* **1a** (0.24 mmol), **2a** (0.2 mmol), catalyst, oxidant (2 equiv), solvent (2 mL), CH_3NO_2:other solvents = 0.5:1.5 mL, 90 °C, 8 h.
[b] Isolated yield.
[c] The reaction was carried out at 70 °C.
[d] The reaction was carried out at 110 °C

chose the mixture CH_3NO_2/DMF as the reaction solvent. Next, the reactions were carried out with different oxidants. Ag_2CO_3, BPO and *t*-BuOOBu-*t*, 6-dicyanobenzoquinone (DDQ), $CO(NH_2)_2{\cdot}H_2O_2$, and TBHP showed no or slight effects to promote the reaction, but using air gave the same yield as what was got under O_2 (entries 10–16). Then, we investigated the reactions at different loadings of $FeCl_3$. The yield of **3aa** was further improved by increasing the amount of $FeCl_3$ gradually. When the reaction was carried out with 30 mol% $FeCl_3$, the yield of **3aa** was increased to 62%, but the higher loading (>30 mol%) resulted in reduced yield (entries 16–19). Finally, the catalysts screening was done. Some generally used catalysts including CuI, $FeBr_3$, $Fe(OTf)_3$, $FeCl_3$ and $Fe(acac)_3$ were tested, and $FeCl_3$ was found to be the best one (entries 20–23). Besides, increasing the temperature to 110 °C did not enhance the yield. At the temperature of 70 °C, the yield decreased sharply (entries 24 and 25). Increasing the reaction time also did not enhance the yield. Thus, 30 mol% $FeCl_3$, 90 °C and CH_3NO_2/DMF are the optimal conditions for this reaction.

Under the optimized reaction conditions, various aldehydes **2** were found to be suitable reaction partners with *N*-phenylbenzamidine **1a** to provide the corresponding 1,2,4-trisubstituted imidazoles derivatives **3** (Table 2). It could be seen that electronic effects played a significant role: benzaldehydes with electron-donating groups such as methyl and methoxy proceeded with good yields (entries 1–6), but the dimethylamino did not give the expected product (entry 15). Benzaldehydes with electron-withdrawing groups such as chloro, fluoro, cyano and trifluoro-

Table 2. Reactions of *N*-phenylbenzamidine with various aldehydes.[a]

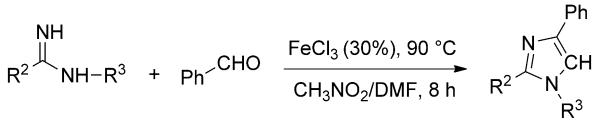


1a 2 3

Entry	R^1	Product	Yield [b]
1	C_6H_5 (**2a**)	**3aa**	62%
2	4-$CH_3C_6H_4$ (**2b**)	**3ab**	64%
3	4-$CH_3OC_6H_4$ (**2c**)	**3ac**	70%
4	2-$CH_3OC_6H_4$ (**2d**)	**3ad**	61%
5	3,4-$CH_3OC_6H_3$ (**2e**)	**3ae**	66%
6	3,4-$CH_3C_6H_3$ (**2f**)	**3af**	59%
7	4-ClC_6H_4 (**2g**)	**3ag**	57%
8	2-ClC_6H_4 (**2h**)	**3ah**	52%
9	4-F C_6H_4 (**2i**)	**3ai**	60%
10	3-F C_6H_4 (**2j**)	**3aj**	61%
11	4-$CF_3C_6H_4$ (**2k**)	**3ak**	56%
12	4-CN C_6H_4 (**2l**)	**3al**	40%
13	4-$NO_2C_6H_4$ (**2m**)	**3am**	0%
14	2-$NO_2C_6H_4$ (**2n**)	**3an**	0%
15	4-$NMe_2C_6H_4$ (**2o**)	**3ao**	0%
16	*n*-C_3H_7 (**2p**)	**3ap**	57%
17	*n*-C_5H_{11} (**2q**)	**3aq**	55%
18	*n*-$C_{11}H_{23}$ (**2r**)	**3ar**	51%
19	2,6-dimethylhept-5-enyl (**2s**)	**3as**	41%

[a] *Reaction conditions:* **1a** (0.24 mmol), **2a–s** (0.2 mmol), $FeCl_3$ (30% mmol), CH_3NO_2: DMF = 0.5:1.5 mL, 90 °C, 8 h.
[b] Isolated yield.

Table 3. Reactions of benzaldehyde with various *N*-arylbenzamidines.[a]



1 2a 3

Entry	R^2	R^3	Product	Yield[b]
1	C_6H_5	C_6H_5	**3aa**	62%
2	C_6H_5	4-$CH_3C_6H_4$	**3ba**	72%
3	4-$CH_3C_6H_4$	C_6H_5	**3ca**	71%
4	C_6H_5	3-$CH_3C_6H_4$	**3da**	62%
5	C_6H_5	4-$CH_3OC_6H_4$	**3ea**	75%
6	C_6H_5	2-$C_2H_5C_6H_4$	**3fa**	61%
7	C_6H_5	4-ClC_6H_4	**3ga**	58%
8	C_6H_5	3-ClC_6H_4	**3ha**	54%
9	2-ClC_6H_4	C_6H_5	**3ia**	52%
10	4-$CH_3C_6H_4$	4-$CH_3C_6H_4$	**3ja**	71%
11	4-$CH_3OC_6H_4$	4-$CH_3C_6H_4$	**3ka**	76%
12	3-pyridinyl	C_6H_5	**3la**	57%
13	*t*-Bu	C_6H_5	**3ma**	0%
14	C_6H_5	C_2H_5	**3na**	0%
15	C_6H_5	4-$NO_2C_6H_4$	**3oa**	0%

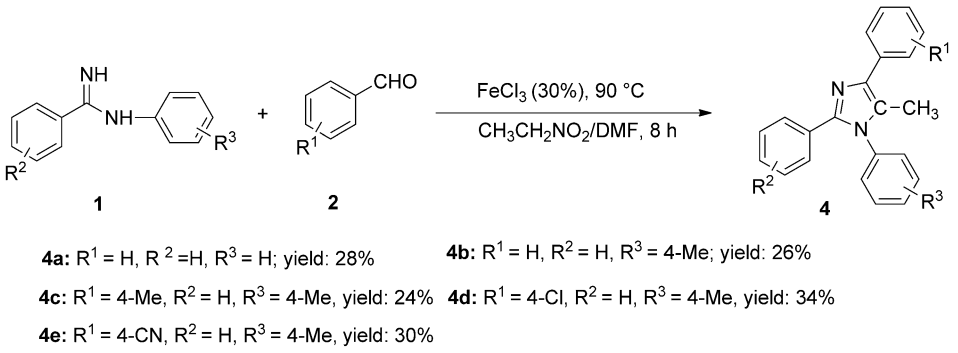
[a] *Reaction conditions:* **1a–o** (0.24 mmol), **2a** (0.2 mmol), $FeCl_3$ (30% mmol), CH_3NO_2:DMF = 0.5:1.5 mL, 90 °C, 8 h.
[b] Isolated yield

methyl groups gave lower but still acceptable yields (entries 7–12). However, the desired product could not be obtained when a strong electron-withdrawing group such as nitro was present (entries 13 and 14). Aliphatic aldehydes were suitable substrates to produce 1,2,4-trisubstituted imidazoles in good yield (entry 16–19). Besides, the 2-substituted benzaldehydes showed slightly lower yields than the 4-substituted ones (entries 3, 4, 7 and 8), which was probably caused by steric effects.

To study the scope and generality of the present protocol, various *N*-arylbenzamidines were studied for the oxidative C–H/N–H bond cycloaddition reactions with benzaldehyde under the above optimized reaction conditions. As shown in Table 3, the most of investigated *N*-arylbenzamidines were suitable partners for the oxidative C–H/N–H bond cycloaddition reactions and provided the corresponding products in moderate yields. In general, *N*-arylbenzamidines with electron-donating groups (such as methyl, methoxy and ethyl) on R^2 and/or R^3 provided higher yields of the desired product (entries 1–6). Especially, when the *N*-arylbenzamidines bearing two electron-donating groups were employed, the yields were up to 76% (entries 10 and 11). Benzamidines with electron-withdrawing groups (such as chloro) gave lower but still acceptable yields (entries 7–9), but the strongly electron-withdrawing substituted *N*-arylbenzamidines [such as *N*-(4-nitrophenyl)benzamidine, **1o**] did not give the expect product (entry 15). Moreover, the amidines with aliphatic groups, such as *N*-phenylpivalamidine **1m** and *N*-ethylbenzamidine **1n** did not give the expected product (entries 13 and 14). The 4-substituted benzamidines showed slightly higher yields than the 3-substituted ones (entries 3, 4, 7 and 8). Notably, *N*-phenylnicotinamidine **2l** could also be suitable for the cycloaddition reactions and provided the corresponding product **3la** with 57% yield (entry 12).

The synthesis of 1,2,4,5-tetrasubstituted imidazoles through the reactions of amidines and aldehydes was performed in $CH_3CH_2NO_2$/DMF (1:3), with $FeCl_3$ (30%) as catalyst at 90 °C for 8 h (Scheme 1). It was found that the corresponding 1,2,4,5-tetrasubstituted imidazoles **4a**, **4b**, **4c**, **4d**, **4e** were obtained in only 24–34% yield. This was probably due to steric effects.

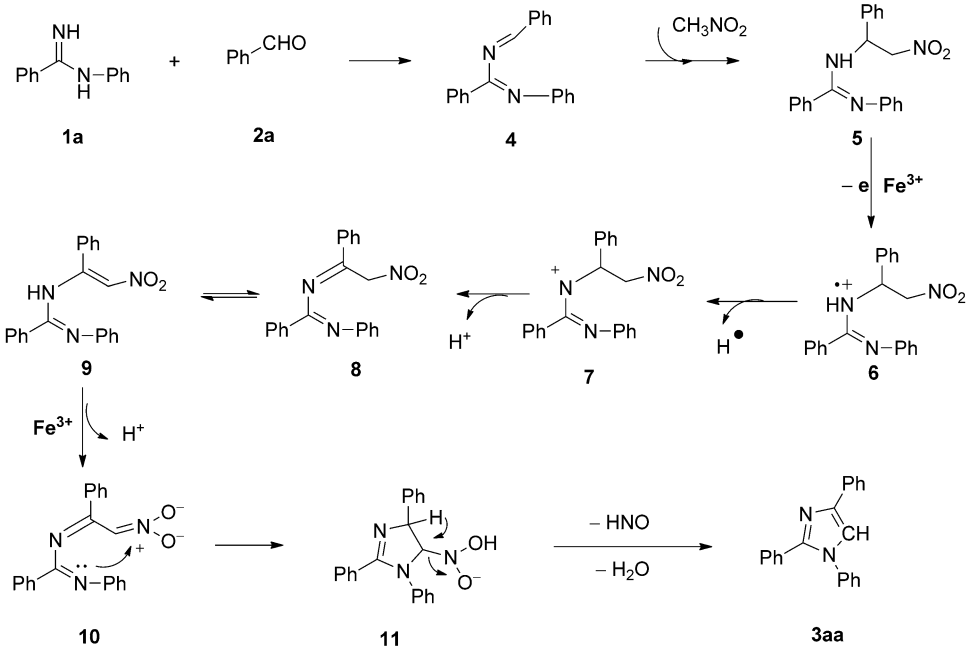
To probe the mechanism of the reactions, several control experiments were performed. While the reaction was carried out with *N*-phenylbenzamidine **1a** (0.24 mmol), benzaldehyde **2a** (0.20 mmol), CH_3NO_2 (0.40 mmol) in the presence of $FeCl_3$ (30 mol%) in DMF at 90 °C under an atmosphere of air for 8 h, the desired product **3aa** was obtained in 25% yield. The



Scheme 1. Synthesis of 1,2,4,5-tetrasubstituted imidazoles.

cycloaddition reaction did not occur without participation of CH_3NO_2. Therefore, nitromethane could provide a carbon atom for the reaction. Imidazole **3aa** was also obtained in 62% yield *via* reaction of **1a** with **2a** under N_2-protected conditions. Thus, we speculate the the NO_2 group was the terminal oxidant in this process. Based on the above observations and the analogous mechanisms discussed in the literature,[13] a plausible mechanism was proposed as shown in Scheme 2. First, the intermediate **4** was produced by the condensation reaction of *N*-phenylbenzamidine **1a** with benzaldehyde **2a**. Then the intermediate **5** was produced from Michael addition of intermediate **4** with CH_3NO_2. Subsequently, the iron catalyst oxidized the intermediate **5** into the radical cation **6**, and the intermediate **7** was obtained from intermediate **6** after subsequent removal of a hydrogen radical. Next, the intermediate **7** underwent proton abstraction with the oxidant forming intermediate **8**, which further isomerized into enamine **9** smoothly. Then, iron-catalyzed synthesis of radical cation **10** from **9** occurred *via* loss of a proton. Finally, the product **3aa** was obtained *via* the intramolecular Michael addition with removal of nitroxyl (HNO) and H_2O abstraction from intermediate **11**, which was produced from **10**.

In conclusion, we have developed an efficient iron(III)-catalyzed synthesis of 1,2,4-trisubstituted imidazoles through the reactions of amidines and aldehydes in air. Five hydrogen dissociations involving C–H and N–H bonds activation are realized under mild conditions in this approach. The procedure is sustainable, simple and economic. This procedure useds $FeCl_3$ as the catalyst which is less toxic than the copper catalyst. Comparing with the literature methods, this methodology has several advantages, such as commercial starting materials, multicomponent reaction in one-pot, use of base-free and ligand-free conditions, under air.



Scheme 2. A plausible reaction mechanism.

Experimental Section

Typical Procedure for the Reaction between Amidines and Benzaldehydes: Synthesis of 1,2,4-Triphenyl-1*H*-imidazole (3aa)

All reactions were performed on a 0.20-mmol scale relative to aldehydes. The *N*-phenylbenzamidine (**1a**, 0.24 mmol), benzaldehyde (**2a**, 0.2 mmol), $FeCl_3$ (0.060 mmol) and 2 mL $MeNO_2$/DMF (1:3) were charged in a round-bottom flask equipped with a stirrer. The resulting mixture was stirred for 8 h at 90 °C. After cooling to room temperature, the reaction mixture was treated with water (2 mL), and extracted with ethyl acetate (3×10 mL). The combined organic phases were washed with brine (2×5 mL), dried over anhydrous $MgSO_4$ and concentrated under vacuum. The residue was subjected to flash column chromatography with hexanes/EtOAc (20/1) as eluent to obtain the desired **3aa** as a light yellow oil; yield: 62%. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.87–7.90 (d, *J* = 9.0 Hz, 2H), 7.21–7.45 (m, 14H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 146.9, 141.6, 138.4, 133.8, 130.2, 129.4, 129.1, 128.7, 128.5, 128.4, 128.1, 126.9, 125.7, 125.0, 118.5. ESI HR-MS: *m/z* = 296.1316, calcd. for $C_{21}H_{16}N_2$ $[M+H]^+$: 296.1313.

The remaining 1,2,4-trisubstituted imidazoles were prepared in a similar manner.

Acknowledgements

We are grateful for financial support from the National Science Foundation of P. R. of China (No. 21372102) and the Project of National Science Foundation of Gansu Province P. R. China (No. 1208RJZA266).

References

[1] a) A. Gazit, H. App, G. McMahon, J. Chen, A. Levitzki, F. D. Bohmer, *J. Med. Chem.* **1996**, *39*, 2170; b) G. Sakata, K. Makino, Y. Kurasawa, *Heterocycles* **1988**, *27*, 2481; c) W. He, M. R. Myers, B. Hanney, A. P. Sapada, G. Bilder, H. Galz-cinski, D. Amin, S. Needle, K. Page, Z. Jayyosi, M. H. Perrone, *Bioorg. Med. Chem. Lett.* **2003**, *13*, 3097; d) Y. B. Kim, Y. H. Kim, J. Y. Park, S. K. Kim, *Bioorg. Med. Chem. Lett.* **2004**, *14*, 541; e) U. Sehlstedt, P. Aich, J. Bergman, H. Vallberg, B. Norden, A. Graslund, *J. Mol. Biol.* **1998**, *278*, 31.

[2] R. H. Sarges, R. Howard, R. G. Browne, L. A. Lebel, P. A. Seymour, *J. Med. Chem.* **1990**, *33*, 2240.

[3] a) D. T. Mowry, *Chem. Rev.* **1948**, *43*, 189; b) G. P. Ellis, T. M. Romney-Alexandar, *Chem. Rev.* **1987**, *87*, 779; c) R. G. R. Bacon, H. A. O. Hill, *J. Chem. Soc.* **1964**, 1097; d) T. Sandmeyer, *Ber. Dtsch. Chem. Ges.* **1884**, *17*, 2650; e) C. F. Koelsch, A. G. Whitney, *J. Org. Chem.* **1941**, *6*, 795.

[4] a) K. Mori, K. Yamaguchi, T. Mizugaki, K. Ebitani, K. Kaneda, *Chem. Commun.* **2001**, 461; b) K. Yamaguchi, N. Mizuno, *Angew. Chem.* **2003**, *115*, 1518; c) M. Kotani, T. Koike, K. Yamaguchi, N. Mizuno, *Green Chem.* **2006**, *8*, 735; d) F. Li, J. Chen, Q. Zhang, Y. Wang, *Green Chem.* **2008**, *10*, 553; e) Y. Zhang, K. Xu, X. Chen, T. Hu, Y. Yu, J. Zhang, J. Hung, *Catal. Commun.* **2010**, *11*, 951.

[5] a) M. L. Mihailović, A. Stojiljikovi, V. Andrewjevi, *Tetrahedron Lett.* **1965**, 461; b) T. Kajimoto, H. Takahashi, J. Tsuji, *J. Org. Chem.* **1976**, *41*, 1389; c) W. P. Griffith, B. Reddy, A. G. F. Shoair, M. Suriaatmaja, A. J. P. White, D. J. Williams, *J. Chem. Soc. Dalton Trans.* **1998**, 2819.

[6] a) P. Capdevielle, A. Lavigne, D. Sparfel, J. Baranne-Lafont, M. Maumy, *Tetrahedron Lett.* **1990**, *31*, 3305; b) R. Tang, S. E. Di-amond, N. Neary, F. Marks, *J. Chem. Soc. Perkin Trans. 1* **1978**, 562; c) F. Porta, C. Crotti, S. Cennini, *J. Mol. Catal.* **1989**, *50*, 333; d) A. Bailey, B. R. James, *Chem. Commun.* **1996**, 2343; e) Y. Maeda, T. Nishimura, S. Uemura, *Bull. Chem. Soc. Jpn.* **2003**, *76*, 2399.

[7] a) A. R. Karimi, Z. Alimohammadi, J. Azizian, A. A. Mohammadi, M. R. Mohammadizadeh, *Catal. Commun.* **2006**, *7*, 728; b) S. Samai, G. C. Nandi, P. Singh, M. S. Singh, *Tetrahedron* **2009**, *65*, 10155; c) M. M. Heravi, F. Derikvand, M. Haghighi, *Monatsh.-Chem.* **2008**, *139*, 31; d) B. Sadeghi, B. B. F. Mirjalili, M. M. Hashemi, *Tetrahedron Lett.* **2008**, *49*, 2575.

[8] a) S. Balalaie, A. Arabanian, *Green Chem.* **2000**, *2*, 274; b) M. Kidwai, P. Mothsra, V. Bansal, R. K. Somvanshi, A. S. Ethayathulla, S. Dey, T. P. Singh, *J. Mol. Catal. A: Chem.* **2007**, *265*, 177; c) S. Kantevari, S. V. N. Vuppalapati, D. O. Biradar, L. Nagarapu, *J. Mol. Catal. A: Chem.* **2007**, *266*, 109; d) M. M. Heravi, F. Derikvand, F. F. Bamoharram, *J. Mol. Catal. A: Chem.* **2007**, *263*, 112; e) L. agarapu, S. puri, S. Antevari, *J. Mol. Catal. A: Chem.* **2007**, *266*, 104.

[9] R. L. Yan, H. Yan, C. Ma, Z. Y. Ren, X. A. Cao, G. S. Huang, Y. M. Liang, *J. Org. Chem.* **2012**, *77*, 2024.

[10] J. Li, L. Neuville, *Org. Lett.* **2013**, *15*, 1752.

[11] a) B. Chao, S. Lin, Q. Ma, D. Lu, Y. Hu, *Org. Lett.* **2012**, *14*, 2398; b) X. Yang, Y. Jin, H. Liu, Y. Jiang, H. Fu, *RSC Adv.* **2012**, *2*, 11061; c) L. Xu, Y. Jiang, D. Ma, *Org. Lett.* **2012**, *14*, 1150; d) M. A. McGowan, C. Z. McAvaoy, S. L. Buchwald, *Org. Lett.* **2012**, *14*, 3800; e) S. Li, Z. Li, Y. Yuan, Y. Li, L. Zhang, Y. Wu, *Chem. Eur. J.* **2013**, *19*, 1496; f) B. Li, L. Samp, J. Sagal, C. M. Hayward, C. Yang, Z. Zhang, *J. Org. Chem.* **2013**, *78*, 1273.

[12] D. Tang, P. Wu, X. Liu, Y. X. Chen, S. B. Guo, W. L. Chen, J. G. Li, B. Chen, *J. Org. Chem.* **2013**, *78*, 2746.

[13] a) H. Yan, S. Yang, X. Gao, K. Zhou, C. Ma, R. Yan, G. Huang, *Synlett* **2012**, *23*, 2961; b) H. Shiraishi, T. Nishitani, S. Sakaguchi, Y. Ishii, *J. Org. Chem.* **1998**, *63*, 6234; c) S. Maiti, S. Biswas, U. Jana, *J. Org. Chem.* **2010**, *75*, 1674; d) D. K. Nair, S. M. Mobin, I. N. N. Namboothiri, *Tetrahedron Lett.* **2012**, *53*, 3349; e) W. Y. Huang, Y. C. Chen, K. Chen, *Chem. Asian J.* **2012**, *7*, 688.

