COMMUNICATIONS

Palladium-Catalyzed Asymmetric Hydrogenation of Simple Ketimines Using a Brønsted Acid as Activator

Xiao-Yu Zhou,[a] Ming Bao,[a,*] and Yong-Gui Zhou[b,*]

[a] State Key Laboratory of Fine Chemicals, Dalian University of Technology, 158 Zhongshan Road, Dalian 116012, People's Republic of China
Fax: (+86)-411-3989-3687; phone: (+86)-411-3989-3687; e-mail: mingbao@dlut.edu.cn

[b] State Key Laboratory of Catalysis, Dalian Institute of Chemical Physics, Chinese Academy of Sciences, 457 Zhongshan Road, Dalian 116023, People's Republic of China
Fax: (+86)-411-8437-9220; phone: (+86)-411-8437-9220; e-mail: ygzhou@dicp.ac.cn

Abstract: Using a catalytic amount of a Brønsted acid as activator of simple imines, the highly enantioselective homogeneous palladium-catalyzed asymmetric hydrogenation of simple ketimines was successfully developed with up to 95% *ee*.

Keywords: asymmetric hydrogenation; Brønsted acids; ketimines; palladium catalysis

The preparation of chiral amines from the transition metal-catalyzed asymmetric hydrogenation or transfer hydrogenation of prochiral imines represents one of the most direct and efficient approaches that open a straightforward route to valuable building blocks for natural products, pharmaceuticals and other fine chemical compounds.[1] A variety of chiral metal catalysts has been successfully applied to this reaction over the last few decades. Among the various catalytic systems so far, Ru,[2] Rh,[3] Ir[4] and organocatalysts[5] have been successfully employed in enantioselective hydrogenations and/or transfer hydrogenations of imines. Recently, Zhang and co-workers developed the first asymmetric hydrogenation of unprotected N−H iminiums with up to 95% *ee* using chiral iridium complexes as catalyst.[6] Although significant progress have been made in the enantioselective reduction of imines, the search for new catalytic systems is still highly desirable.

Pd-based catalytic systems have been extensively employed for a wide range of useful synthetic organic transformations,[7] nevertheless, very little attention has been paid to homogeneous asymmetric hydrogenation with chiral Pd complexes. The asymmetric hydrogenations of α-phthalimide ketones and α-keto phosphonates with palladium catalyst systems were reported by us[8] and Goulioukina,[9] respectively. In comparison, there are more reports on Pd-catalyzed asymmetric hydrogenations of activated imines. The first hydrogenation of imino esters catalyzed by palladium complexes was described by Amii[10] and co-workers with up to 91% *ee* in 2001. Afterwards, highly enantioselectively Pd-catalyzed hydrogenations of *N*-diphenylphosphinyl ketimines and *N*-tosylimines were reported by us[11] and the Zhang[12] group, respectively [Scheme 1, Eq. (1)]. Since then, chiral palladium complexes have also been employed for the asymmetric hydrogenation of some other cyclic activated sulfonylimines in our laboratory.[13] In 2009, Rubio-Pérez[14] and co-workers reported the direct reductive amination of alkyl ketones catalyzed by chiral palladium complexes at 70°C with up to 99% *ee*, but only moderate yield and low enantiomeric excess were observed in the amination of aryl ketones. Most recently, an efficient Pd-catalyzed asymmetric hydrogenation of simple indoles was developed by us with a Brønsted acid as activator.[15] Although much effort
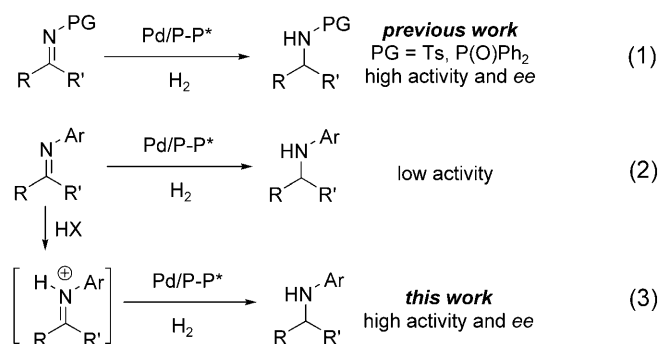
Scheme 1. Activation strategy for Pd-catalyzed asymmetric hydrogenation of simple ketimines.

has been successfully made in the asymmetric hydrogenation of functionalized ketones and activated imines, there is no report on the highly enantioselective, Pd-catalyzed hydrogenation of simple ketimines due to the low activity of simple ketimines.

Accordingly, Ru-, Rh- and Ir-catalyzed asymmetric hydrogenations of quinolines[17] and imines[6] revealed that the addition of a Brønsted acid is one of the key factors for both high reactivity and enantioselectivity. These results encouraged us to stick to our initial hypothesis, which is to employ a catalytic amount of a Brønsted acid as an activator in the Pd-catalyzed hydrogenation of simple ketimines [Scheme 1, Eq. (3)]. Herein, we report our preliminary results on the Pd-catalyzed asymmetric hydrogenation of simple ketimines using a Brønsted acid as activator with up to 95% *ee*.

Our initial study began with *N*-(4-methoxyphenyl) (PMP) imine **1a** as the model substrate and Pd(OCOCF₃)₂/(S)-SynPhos as the catalyst on the basis of our previous successful hydrogenations of functionalized ketones[8] and activated imines.[11,13] However, low conversion (49% conversion) and an almost racemic product were observed in the hydrogenation of imine **1a** (Table 1, entry 1), and the re-
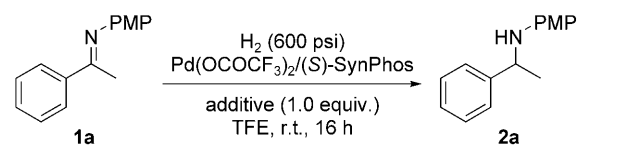
peatability was also poor. To enhance the activity of imines, a number of Brønsted acids was tested, the results are summarized in Table 1. When one equivalent of CF₃CO₂H was added, both the conversion and enantioselectivity (30% *ee*) were drastically improved (Table 1, entries 1 *vs.* 2). Other achiral acids also gave full conversions but still with low enantioselectivities (entries 3 and 4). Next, some commercially available chiral acids were also tested, (*S*)-mandelic acid provided complete conversion and slightly high enantioselectivity (50% *ee*, entry 5). Pleasingly, the addition of tartaric acid and its derivatives proceeded with moderate enantioselectivities (46–68% *ee*s, entries 6–10) and full conversions. Di-*p*-toluoyl-L-tartaric acid (L-DTTA) gave the highest *ee* (68%, entry 10). It is noteworthy that the L-configuration of DTTA matches with the (*S*)-configuration of the axial chiral bisphosphine ligands, and the configuration of the product is controlled by chiral palladium catalysts. The effect of the amount of activator L-DTTA on the activity and *ee* was investigated, slightly low enantioselectivity was observed when the amount of L-DTTA was reduced to 10 mol% (entry 11), gratifyingly, the hydrogenation reaction proceed smoothly with the best 68% *ee* in the presence of 20 mol% L-DTTA (entry 12). Then, different solvents were tested, and a strong solvent-dependent phenomenon was observed. MeOH and CH₂Cl₂ led to very low reactivity (entries 13 and 14); TFE was found to be the optimal solvent, which is in accordance with the Pd-catalyzed hydrogenation of ketones and activated imines in the literature.[8–16]

Subsequently, some commercially available bisphosphine ligands were examined under the above conditions. The results showed that axial chiral bidentate bisphosphine ligands **L1–L4** and **L6–L8** (Table 2, entries 1–4 and 6–8) gave full conversions with 58–75% *ee*. No catalytic activity was observed for the (*R,R*)-Me-DuPhos ligand. (*R*)-C₄-TunePhos gave the the highest *ee* (75%, entry 7). A decrease of the reaction temperature does not enhance the enantioselectivity (entry 9). Therefore, the optimized conditions are: Pd(OCOCF₃)₂/(*R*)-C₄-TunePhos/D-DTTA/TFE.

Under the optimal reaction conditions, a variety of *N*-arylimines **1a–i** was subjected to asymmetric hydrogenation, as shown in Table 3. For the imines **1a–d** with different substituents on the N-atom (Table 3, entries 1–4), full conversions and 64–75% *ee*s were achieved. *N*-(4-methoxyphenyl)imine **1a** gave the highest *ee* (75%). Several acyclic aryl alkyl imines **1e–1i** can be smoothly hydrogenated with 60–72% *ee*s (entries 5–9) regardless of the position and electronic properties of the substituents of the aryl groups.

Interestingly, this catalytic system is particularly effective for the asymmetric hydrogenation of cyclic ketimines **1j–1o** derived from the cyclic ketone, 1-tetralone, 88–95% *ee*s were achieved (Table 3, en-

Table 1. The effect of the Brønsted acids and solvents.[a]

Entry	Brønsted Acids	Conversion [%][b]	*ee* [%][c]
1	none	49	5
2	CF₃CO₂H	>95	30
3	C₆H₅CO₂H	>95	37
4	salicylic acid	>95	36
5	(*S*)-mandelic acid	>95	50
6	L-tartaric acid	>95	46
7	L-DBTA	>95	65
8	L-DMTA	>95	64
9	D-DTTA	>95	65
10	L-DTTA	>95	68
11[d]	L-DTTA	>95	54
12[e]	L-DTTA	>95	68
13[e,f]	L-DTTA	34	2
14[e,g]	L-DTTA	45	59

[a] *Reaction conditions:* 2 mol% Pd-chiral ligand complex generated from Pd(OCOCF₃)₂ and (S)-SynPhos in acetone, H₂ (600 psi), TFE (2 mL), 1.0 equiv. of additive, room temperature, 16 h.
[b] Determined by ¹H NMR.
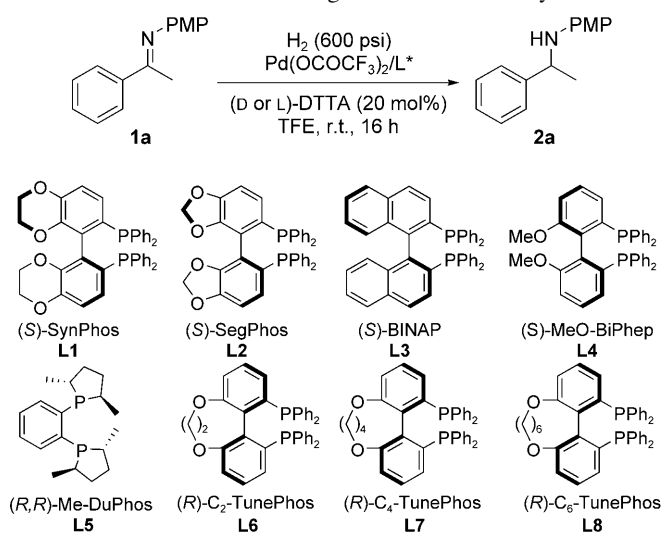[c] Determined by HPLC.
[d] 10 mol% L-DTTA was added.
[e] 20 mol% L-DTTA was added.
[f] Methanol as solvent.
[g] CH₂Cl₂ as solvent.

Table 2. The effect of chiral ligands on the activity and *ee*.[a]

Entry	L*	Conversion [%][b]	*ee* [%][c]
1	**L1**	>95	68 (*S*)
2	**L2**	>95	58 (*S*)
3	**L3**	>95	71 (*S*)
4	**L4**	>95	73 (*S*)
5	**L5**	<5	N/A
6[d]	**L6**	>95	54 (*R*)
7[d]	**L7**	>95	75 (*R*)
8[d]	**L8**	>95	72 (*R*)
9[d,e]	**L7**	>95	75 (*R*)

[a] *Reaction conditions:* 2 mol% Pd-chiral ligand complex generated from Pd(OCOCF$_3$)$_2$ and chiral ligand in acetone, H$_2$ (600 psi), TFE (2 mL), 20 mol% L-DTTA, room temperature, 16 h.
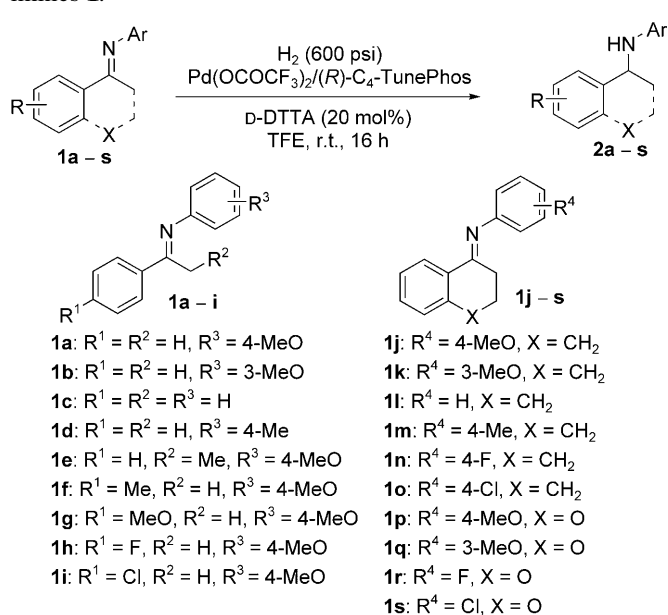[b] Determined by ^{1}H NMR.
[c] Determined by HPLC.
[d] D-DTTA was used.
[e] Carried out at 10 °C.

tries 10–15). For the cyclic imines **2p–2s** derived from 4-chromanone, 86–93% *ee* were obtained under the standard conditions (entries 16–19). The above approach provides a facile access to chiral cyclic amines containing 1,2,3,4-tetrahydronanphthyl-1-amine and 3,4-dihydro-*2H*-chromen-4-amine frameworks, types of privileged structural motif present in a large number of drugs and natural compounds.[18]

In summary, using a catalytic amount of a Brønsted acid as activator of simple imines, the highly enantioselective homogeneous Pd-catalyzed asymmetric hydrogenation of simple ketimines was successfully developed with up to 95% *ee*. Our ongoing experiments are focused on the asymmetric hydrogenation of other substrates and investigations of the reaction mechanism.

Table 3. Pd-catalyzed asymmetric hydrogenation of ketimines **1**.[a]

1a: R^1 = R^2 = H, R^3 = 4-MeO
1b: R^1 = R^2 = H, R^3 = 3-MeO
1c: R^1 = R^2 = R^3 = H
1d: R^1 = R^2 = H, R^3 = 4-Me
1e: R^1 = H, R^2 = Me, R^3 = 4-MeO
1f: R^1 = Me, R^2 = H, R^3 = 4-MeO
1g: R^1 = MeO, R^2 = H, R^3 = 4-MeO
1h: R^1 = F, R^2 = H, R^3 = 4-MeO
1i: R^1 = Cl, R^2 = H, R^3 = 4-MeO

1j: R^4 = 4-MeO, X = CH$_2$
1k: R^4 = 3-MeO, X = CH$_2$
1l: R^4 = H, X = CH$_2$
1m: R^4 = 4-Me, X = CH$_2$
1n: R^4 = 4-F, X = CH$_2$
1o: R^4 = 4-Cl, X = CH$_2$
1p: R^4 = 4-MeO, X = O
1q: R^4 = 3-MeO, X = O
1r: R^4 = F, X = O
1s: R^4 = Cl, X = O

Entry	Ketimines **1**	Yield [%][b] (Product)	*ee* [%][c]
1	**1a**	84 (**2a**)	75 (*R*)
2	**1b**	95 (**2b**)	71 (+)
3	**1c**	92 (**2c**)	70 (−)
4	**1d**	96 (**2d**)	64 (+)
5	**1e**	78 (**2e**)	68 (+)
6	**1f**	98 (**2f**)	72 (+)
7	**1g**	91 (**2g**)	60 (+)
8	**1h**	99 (**2h**)	64 (−)
9	**1i**	92 (**2i**)	63 (+)
10	**1j**	95 (**2j**)	94 (+)
11	**1k**	92 (**2k**)	90 (+)
12	**1l**	95 (**2l**)	95 (+)
13	**1m**	98 (**2m**)	92 (+)
14	**1n**	92 (**2n**)	95 (+)
15	**1o**	97 (**2o**)	88 (+)
16	**1p**	89 (**2p**)	93 (+)
17	**1q**	98 (**2q**)	91 (+)
18	**1r**	84 (**2r**)	93 (+)
19	**1s**	97 (**2s**)	86 (+)

[a] *Reaction conditions:* 2 mol% Pd-chiral ligand complex generated from Pd(OCOCF$_3$)$_2$ and (*R*)-C$_4$-TunePhos in acetone, H$_2$ (600 psi), TFE (2 mL), 20 mol% D-DTTA, room temperature, 16 h. The conversions are >95%.
[b] Isolated yield.
[c] Determined by HPLC.

Experimental Section

General Procedure for the Pd-Catalyzed Asymmetric Hydrogenation of Ketimines

In a flame-dried Schlenk tube equipped with septum cap and stirring bar, Pd(OCOCF$_3$)$_2$ (2 mol%, 0.005 mmol) and (*R*)-C$_4$-TunePhos (2.4 mol%, 0.006 mmol) were dissolved in

dry acetone and stirred under nitrogen at room temperature for 1 h. The solvent was removed under vacuum to give the catalyst. This catalyst was taken into a glove box filled with nitrogen and dissolved in dry TFE (2 mL). To the ketimines **1** (0.25 mmol) and D-DTTA (20 mol%, 0.05 mmol) was added this catalyst solution, and then the mixture was transferred to an autoclave. The autoclave was stirred at room temperature for 16 h. After release of the hydrogen, the autoclave was opened and saturated $NaHCO_3$ solution was added. The organic phase was separated and the aqueous layer was extracted with CH_2Cl_2. The combined organic phases were dried over Na_2SO_4, concentrated under reduced pressure, and purified by flash chromatography on silica gel to yield the corresponding product **2**. The enantiomeric excess was determined by HPLC.

(+)-*N*-(4-Methoxyphenyl)-3,4-dihydro-*2H*-chromen-4-amine (2p): Colourless oil; yield: 89%; 93% *ee*, $[\alpha]_D^{22}$: 39.2 (*c* 0.92, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 2.03–2.06$ (t, $J = 6.04$ Hz, 2H), 3.65–3.71 (m, 4H), 4.15–4.18 (t, $J = 4.60$ Hz, 2H), 4.48 (s, 1H), 6.58–6.60 (d, $J = 8.72$ Hz, 2H), 6.77–6.87 (m, 4H), 7.13–7.16 (t, $J = 7.88$ Hz, 1H), 7.27–7.29 (d, $J = 7.56$ Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 28.0$, 47.7, 55.9, 62.8, 114.4, 115.2, 117.1, 120.7, 123.7, 129.1, 130.2, 140.9, 152.3, 155.1; HR-MS: $m/z = 256.1342$, calculated for $C_{16}H_{18}NO_2$ $[M+H]^+$: 256.1338; HPLC (IC, *i*-PrOH/hexane 5/95, 0.8 mL min^{-1}, 254 nm): $t_1 = 10.4$ min, $t_2 = 11.5$ min.

Acknowledgements

References

[1] a) H.-U. Blaser, B. Pugin, F. Spindler, *Applied Homogeneous Catalysis with Organometallic Compounds*, 2nd edn., (Eds.: B. Cornils, W. A. Herrmann), Wiley-VCH, Weinheim, **2000**, Chapter 3.3.1; b) *Comprehensive Asymmetric Catalysis*, (Eds.: E. N. Jacobsen, A. Pfaltz, H. Yamamoto), Springer, New York, **1999**; c) *The Handbook of Homogeneous Hydrogenation*, (Eds.: J. G. de Vries, C. J. Elsevier), Wiley-VCH, Weiheim, Germany, **2007**.

[2] a) N. Uematsu, A. Fujii, S. Hashiguchi, T. Ikariya, R. Noyori, *J. Am. Chem. Soc.* **1996**, *118*, 4916; b) J. S. M. Samec, J.-E. Bäckvall, *Chem. Eur. J.* **2002**, *8*, 2955; c) L. F. Tietze, N. Rackelmann, I. Müller, *Chem. Eur. J.* **2004**, *10*, 2722; d) C. P. Casey, J. B. Johnson, *J. Am. Chem. Soc.* **2005**, *127*, 1883; e) C. P. Casey, G. A. Bikzhanova, Q. Cui, I. A. Guzei, *J. Am. Chem. Soc.* **2005**, *127*, 14062; f) J. S. M. Samec, A. H. Éll, J. B. Åberg, T. Privalov, L. Eriksson, J.-E. Bäckvall, *J. Am. Chem. Soc.* **2006**, *128*, 14293; g) J. Wu, F. Wang, Y. Ma, X. Cui, L. Cun, J. Zhu, J. Deng, B. Yu, *Chem. Commun.* **2006**, 1766; h) J. E. D. Martins, G. J. Clarkson, M. Wills, *Org. Lett.* **2009**, *11*, 847.

[3] a) M. J. Burk, J. E. Feaster, *J. Am. Chem. Soc.* **1992**, *114*, 6266; b) J. Mao, D. C. Baker, *Org. Lett.* **1999**, *1*, 841; c) V. I. Tararov, R. Kadyrov, T. H. Riermeire, A. Börner, *Adv. Synth. Catal.* **2002**, *344*, 200; d) C. Li, J. Xiao, *J. Am. Chem. Soc.* **2008**, *130*, 13208.

[4] a) D. Xiao, X. Zhang, *Angew. Chem.* **2001**, *113*, 3533; *Angew. Chem. Int. Ed.* **2001**, *40*, 3425; b) Y. Chi, Y.-G. Zhou, X. Zhang, *J. Org. Chem.* **2003**, *68*, 4120; c) X.-B. Jiang, A. J. Minnaard, B. Hessen, B. L. Feringa, A. L. L. Duchateau, J. G. O. Andrien, J. A. F. Boogers, J. G. de Vries, *Org. Lett.* **2003**, *5*, 1503; d) M. Solinas, A. Pfaltz, P. G. Cozzi, W. Leitner, *J. Am. Chem. Soc.* **2004**, *126*, 16142; e) A. Trifonova, J. S. Diesen, C. J. Chapman, P. G. Andersson, *Org. Lett.* **2004**, *6*, 3825; f) C. Moessner, C. Bolm, *Angew. Chem.* **2005**, *117*, 7736; *Angew. Chem. Int. Ed.* **2005**, *44*, 7564; g) S.-F. Zhu, J.-B. Xie, Y.-Z. Zhang, S. Li, Q.-L. Zhou, *J. Am. Chem. Soc.* **2006**, *128*, 12886; h) Q. Yang, G. Shang, W. Gao, J. Deng, X. Zhang, *Angew. Chem.* **2006**, *118*, 3916; *Angew. Chem. Int. Ed.* **2006**, *45*, 3832; i) A. Trifonov, J. S. Diesen, P. G. Andersson, *Chem. Eur. J.* **2006**, *12*, 2318; j) M. T. Reetz, O. Bondarev, *Angew. Chem.* **2007**, *119*, 4607; *Angew. Chem. Int. Ed.* **2007**, *46*, 4523; k) C. Li, C. Wang, B. Villa-Marcos, J. Xiao, *J. Am. Chem. Soc.* **2008**, *130*, 14450; l) N. Mršić, A. J. Minnaard, B. L. Feringa, J. G. de Vries, *J. Am. Chem. Soc.* **2009**, *131*, 8358; m) Z. Han, Z. Wang, X. Zhang, K. Ding, *Angew. Chem.* **2009**, *121*, 5449; *Angew. Chem. Int. Ed.* **2009**, *48*, 5345.

[5] a) Z. Wang, X. Ye, S. Wei, P. Wu, A. Zhang, J. Sun, *Org. Lett.* **2006**, *8*, 999; b) Z. Wang, M. Cheng, P. Wu, S. Wei, J. Sun, *Org. Lett.* **2006**, *8*, 3045; c) A. V. Malkov, M. Figlus, S. Stončius, P. Kočovský, *J. Org. Chem.* **2007**, *72*, 1315; d) H. Zheng, J. Deng, W. Lin, X. Zhang, *Tetrahedron Lett.* **2007**, *48*, 7934; e) A. V. Malkov, M. Figlus, P. Kočovský, *J. Org. Chem.* **2008**, *73*, 3985; f) D. Pei, Y. Zhang, S. Wei, M. Wang, J. Sun, *Adv. Synth. Catal.* **2008**, *350*, 619; g) T. Marcelli, P. Hammar, F. Himo, *Chem. Eur. J.* **2008**, *14*, 8562; h) C. Wang, X. Wu, L. Zhou, J. Sun, *Chem. Eur. J.* **2008**, *14*, 8789; i) A. V. Malkov, K. Vranková, S. Stončius, P. Kočovský, *J. Org. Chem.* **2009**, *74*, 5839; j) S. Guizzetti, M. Benaglia, S. Rossi, *Org. Lett.* **2009**, *11*, 2928; k) F.-M. Gautier, S. Jones, S. J. Martin, *Org. Biomol. Chem.* **2009**, *7*, 229.

[6] a) G. Hou, F. Gosselin, W. Li, J. C. McWilliams, Y. Sun, M. Weisel, P. D. O'Shea, C. Chen, I. W. Davies, X. Zhang, *J. Am. Chem. Soc.* **2009**, *131*, 9882; b) G. Hou, R. Tao, Y. Sun, X. Zhang, F. Gosselin, *J. Am. Chem. Soc.* **2010**, *132*, 2124.

[7] a) R. F. Heck, *Pd Reagents in Organic Synthesis*, Academic Press, New York, **1985**; b) E. Negishi, *Handbook of Organopalladium Chemistry for Organic Synthesis*, Wiley, Hoboken, NJ, **2002**; c) J. Tsuji, *Palladium Reagents and Catalysis*, John Wiley & Sons, Chichester, UK, **2004**; d) L. F. Tietze, H. Ila, H. P. Bell, *Chem. Rev.* **2004**, *104*, 3453.

[8] Y.-Q. Wang, S.-M. Lu, Y.-G. Zhou, *Org. Lett.* **2005**, *7*, 3235.

[9] N. S. Goulioukina, G. N. Bondarenko, A. V. Bogdanov, K. N. Gavrilov, I. P. Beletskaya, *Eur. J. Org. Chem.* **2009**, 510.

[10] a) H. Abe, H. Amii, K. Uneyama, *Org. Lett.* **2001**, *3*, 313; b) A. Suzuki, M. Mae, H. Amii, K. Uneyama, *J. Org. Chem.* **2004**, *69*, 5132.

[11] Y.-Q. Wang, Y.-G. Zhou, *Synlett* **2006**, *8*, 1189.

[12] Q. Yang, G. Shang, W. Gao, J. Deng, X. Zhang, *Angew. Chem.* **2006**, *118*, 3916; *Angew. Chem. Int. Ed.* **2006**, *45*, 3832.

[13] a) Y.-Q. Wang, S.-M. Lu, Y.-G. Zhou, *J. Org. Chem.* **2007**, *72*, 3729; b) Y.-Q. Wang, C.-B. Yu, D.-W. Wang, X.-B. Wang, Y.-G. Zhou, *Org. Lett.* **2008**, *10*, 2071; c) C.-B. Yu, D.-W. Wang, Y.-G. Zhou, *J. Org. Chem.* **2009**, *74*, 5633.

[14] L. Rubio-Pérez, F. J. Pérez-Flores, P. Sharma, L. Velasco, A. Cabrera, *Org. Lett.* **2009**, *11*, 265.

[15] D.-S. Wang, Q.-A. Chen, W. Li, C.-B. Yu, Y.-G. Zhou, X. Zhang, *J. Am. Chem. Soc.* **2010**, *132*, 8909.

[16] a) P. Nanayakkara, H. Alper, *Chem. Commun.* **2003**, 2384; b) Y. Tsuchiya, Y. Hamashima, M. Sodeoka, *Org. Lett.* **2006**, *8*, 4851.

[17] a) N. Mrsic, L. Lefort, J. A. F. Boogers, A. J. Minnaard, B. L. Feringa, J. G. de Vries, *Adv. Synth. Catal.* **2008**, *350*, 1081; b) H.-F. Zhou, Z.-W. Li, Z.-J. Wang, T.-L. Wang, L.-J. Xu, Y.-M. He, Q.-H. Fan, J. Pan, L.-Q. Gu, A. S. C. Chan, *Angew. Chem.* **2008**, *120*, 8592; *Angew. Chem. Int. Ed.* **2008**, *47*, 8464; c) Z.-J. Wang, H.-F. Zhou, T.-L. Wang, Y.-M. He, Q.-H. Fan, *Green Chem.* **2009**, *11*, 767; d) Z.-W. Li, T.-L. Wang, Y.-M. He, Z.-J. Wang, Q.-H. Fan, J. Pan, L.-J. Xu, *Org. Lett.* **2008**, *10*, 5265; e) C. Wang, C. Q. Li, X. F. Wu, A. Pettman, J. L. Xiao, *Angew. Chem.* **2009**, *121*, 6646; *Angew. Chem. Int. Ed.* **2009**, *48*, 6524; f) H. Tadaoka, D. Cartigny, T. Nagano, T. Gosavi, T. Ayad, J.-P. Genet, T. Ohshima, V. Ratovelomanana-Vidal, K. Mashima, *Chem. Eur. J.* **2009**, *15*, 9990; g) D.-S. Wang, Y.-G. Zhou, *Tetrahedron Lett.* **2010**, *51*, 3014.

[18] a) N. Kim, S. Lee, K. Y. Yi, S. Yoo, G. Kim, C. O. Lee, S. H. Park, B. H. Lee, *Bioorg. Med. Chem. Lett.* **2003**, *13*, 1661; b) P. D. Buttero, G. Molteni, A. Papagni, T. Pilati, *Tetrahedron: Asymmetry* **2005**, *16*, 971; c) J. Barluenga, A. Mendoza, F. Rodríguez, F. J. Fananas, *Angew. Chem.* **2009**, *121*, 1672; *Angew. Chem. Int. Ed.* **2009**, *48*, 1644.