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COMMUNICATION

Solvent-controlled selective synthesis of biphenols and quinones via oxidative coupling of phenols

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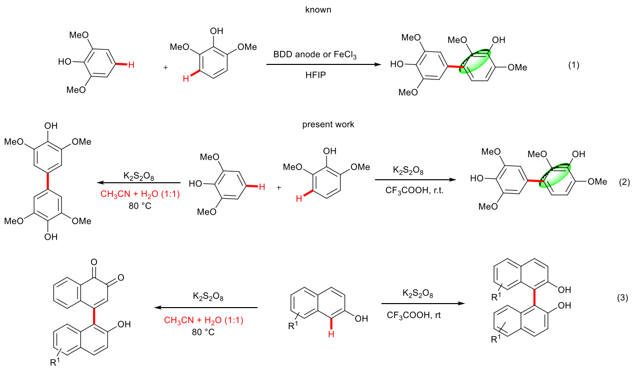
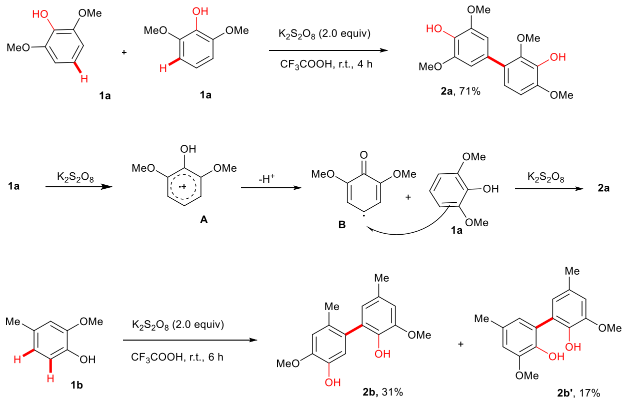
A regioselective synthesis of unsymmetrical and symmetrical biphenols and binaphthols via oxidative coupling of phenols or naphthols in the presence of $K_2S_2O_8$ in CF_3COOH at ambient conditions is described. Interestingly, 1:1 ratio of H_2O and CH_3CN solvent mixtures at 80 °C instead of CF_3COOH provided substituted unsymmetrical quinones. A gram scale synthesis of biphenols and binaphthols was demonstrated.

Biphenols and binaphthols are highly valuable organic molecules and these structural units are present in various biologically active molecules, natural products and functional materials.[1] In addition, these molecules are used as ligands in various organic transformations and enantioselective reactions.[1] The oxidative coupling of phenols or naphthols mediated by metal salts or oxidizing agents is a powerful and easily affordable method to synthesize biphenol and binaphthol molecules in a highly regioselective manner. It is important to note that the nature prefers to synthesize natural products and biomaterials via the oxidative phenol coupling by using oxidative enzymes such as laccase, peroxidase and cytochrome P450 (CYP) as catalysts.[2] Traditionally, biphenols and binaphthols are prepared by the coupling of phenols or naphthols by using a stoichiometric amount of metal salts.[3] Later, the oxidative coupling reaction was carried out with metal catalysts and stoichiometric amount of oxidants.[4] In the meantime, a similar type of coupling reaction has been done by employing organic reagents such as hypervalent iodine(III) reagents, peroxides, DDQ, NaOCl and $NaNO_2$.[5] Subsequently, the oxidative coupling reaction can be achieved via an electrochemical oxidation pathway using boron-doped diamond electrode (eq 1).[6]

The direct oxidative coupling of substituted Guaiacols and phenols to symmetrical biphenols (*ortho-ortho* coupling reaction) by the metal catalysts or organic reagents has been well documented in the literature. For the first time, by applying BDD anode, Waldvogel's group synthesized the unsymmetrical biaryl in the homocoupling reaction of Guaiacol derivative via the radical mechanism.[6a] Very recently, Pappo's group has prepared unsymmetrical biaryl molecule by the homocoupling of Guaiacol derivative in the presence of iron catalyst via radical-anion pathway (eq 1).[4k]



Inspiration by this work and our continuous interest on persulfate chemistry prompted us to explore the possibility of using persulfate reagent for the oxidative coupling of phenols and naphthols.[7] Herein, we report the oxidative dehydrogenative homocoupling of phenols providing unsymmetrical and symmetrical biphenols in the presence of $K_2S_2O_8$ in CF_3COOH at ambient conditions. When 1:1 ratio of H_2O and CH_3CN solvent mixtures was used instead of CF_3COOH, *para-para* coupling biphenols and quinone derivatives were obtained. It is believed that the coupling reaction proceeds via the radical intermediate and the corresponding radical intermediate allows the incoming nucleophiles to attack at the various sites of phenols selectively. Thus, in the reaction, *ortho-ortho*, *ortho-meta*, *meta-para* and *para-para* coupling products were observed from the homocoupling of phenols.



Scheme 1 Cross-coupling of phenols **1a-b**

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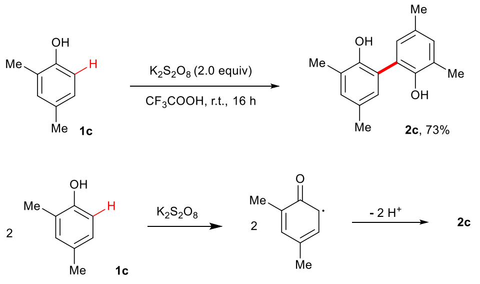
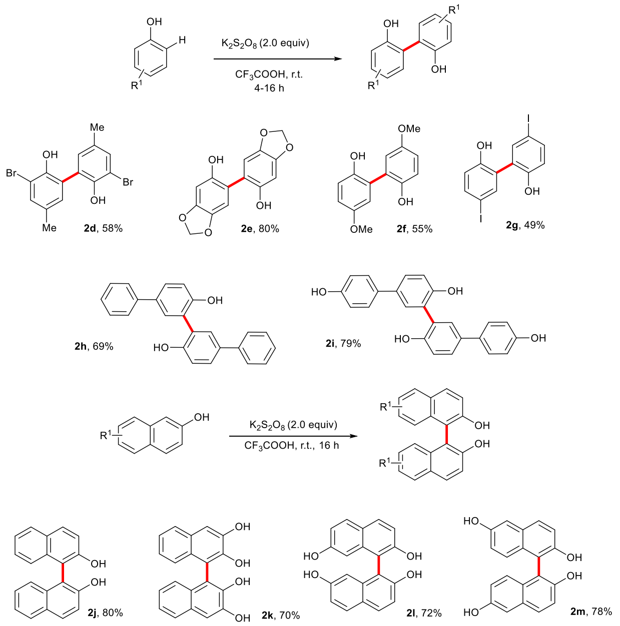
Initialy, the oxidative homocoupling of 2,6-dimethoxylphenol **(1a)** was carried out with $K_2S_2O_8$ in CF_3COOH at room temperature for 4 h. Interestingly, in this reaction, only unsymmetrical biphenol **2a** was observed in 71% yield via the *meta*, *para* C-H coupling corresponding with the hydroxy group of phenol **1a** (Scheme 1). No other competitive symmetrical *ortho-ortho* coupled biphenol was observed in the reaction. The coupling reaction did not proceed without $K_2S_2O_8$. Apart from $K_2S_2O_8,$ the reaction was also examined with $Na_2S_2O_8$, $(NH_4)_2S_2O_8$, $PhI(OAc)_2$ and oxone. Among them, $(NH_4)_2S_2O_8$ was as effective as $K_2S_2O_8$, giving **2a** in 65% yield. $Na_2S_2O_8$ and oxone were partially effective, affording **2a** in 40% and 49% yields, respectively. $PhI(OAc)_2$ inefficient for the reaction. CF_3COOH is also crucial for the reaction. AcOH and *iso*-PrOH solvents were less effective, providing product **2a** in 31% and 23% yields, respectively. Other solvents MeOH, DCE, H_2O and CF_3SO_3H were not effective. The coupling reaction was examined with various amount of $K_2S_2O_8$. Using 1.0 equiv and 1.5 equiv of $K_2S_2O_8,$ product **2a** was observed only in 55% and 66% yields, respectively. With 2.0 equiv of $K_2S_2O_8$, product **2a** was observed in 71% yield (Scheme 1). In this transformation, the naturally occurring Syringol undergoes SET mechanism giving phenol cationic radical intermediate **A** with $K_2S_2O_8$. Further, intermediate **A** was converted into *para*-phenoxyl radical **B** under the reaction conditions (see ESI, page S4-S7). The stability of phenoxyl and phenol cationic radical intermediates was well studied in the literature.[8] Later, intermediate **B** undergoes radical-anion coupling with another molecule **2a** to produce exclusively unsymmetrical biphenol **2a**. Next, the oxidative coupling reaction was examined with 4-methyl-2-methoxy phenol (**1b**) (Scheme 1). In the reaction, interestingly 49% yield of *ortho-meta* coupling unsymmetrical biphenol **2b** along with *ortho-ortho* coupling biphenol **2b'** in 13% yield were observed. Due to the substitution at the *para* position of **1b** could cause of the dropping the yield of *ortho-meta* coupling product **2b**. It is important to note that the 2,4-dimethylphenol (**1c**) provided symmetrical *ortho*, *ortho* coupling product **3a** in 73% yield with $K_2S_2O_8$ in CF_3COOH under ambient conditions (Scheme 2). No other competitive side product was observed in the reaction.

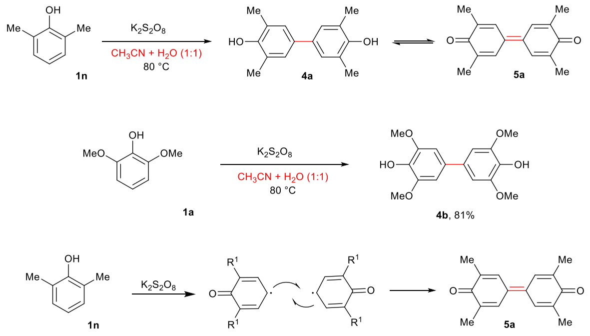


Scheme 2 Homocoupling of 2,4-dimethylphenol (**1c**)

The scope of oxidative coupling reaction was examined with various substituted phenols **1d-i** (Scheme 2). The homocoupling of 2-bromo-4-methylphenol (**1d**) and naturally occurring sesamol (**1e**) proceeded well with $K_2S_2O_8$ giving symmetrical biphenols **2d** and **2e** in 58% and 80% yields, respectively. 4-Methoxy phenol (**1f**) and 4-iodophenol (**1g**) also efficiently participated in the reaction, providing biphenols **2f** and **2g** in 55% and 49% yields, respectively. It is noteworthy that the sensitive iodo and bromo groups were compatible for the reaction. Interestingly, 4-phenylphenol (**1h**) and hydroxyl substituted 4-phenylphenol **1i** afforded the corresponding biphenols **2h** and **2i** in 69% and 79% yields, respectively. Next, the scope of the reaction was examined with naphthols **1j-m**. 2-Naphthol (**1j**) underwent homocoupling efficiently at room temperature giving binaphthol derivative **2j** in 80% yield. A highly useful naphthalene-2,3-diol (**1k**), naphthalene-2,7-diol (**1l**) and naphthalene-2,6-diol (**1m**) provided the corresponding binaphthols **2k-m** in 70%, 72% and 78% yields, respectively. It is important to note that in **1i** and **1l-m**, two hydroxy groups are present on the aromatic ring. Chemoselectively, only one of the hydroxy groups was involved in the coupling reaction. The coupling reaction was not compatible with phenols having electron-withdrawing substituents such as CO_2Me, COMe, F, Cl, NO_2 and Br at the *para* position.



Scheme 3 Scope of phenols and naphthols



Scheme 4 *para-para* Coupling of phenols

A similar type of oxidative coupling reaction was examined with 2,6-dimethyl phenol (**1n**) under the optimized reaction conditions. However, no coupling product was observed. Later, the solvent and temperature optimization was done. When biphasic solvent system that is 1:1 ratio of H_2O and CH_3CN

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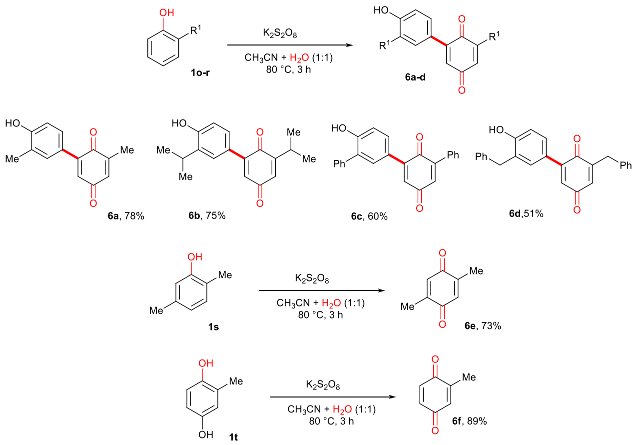
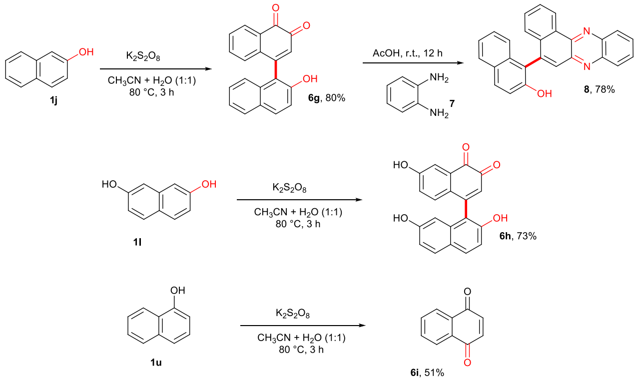
solvent mixtures was used instead of CF_3COOH at 80 °C, the oxidative coupling reaction yielded symmetrical *para-para* coupling biphenol **4a** in 62% yield. Similarly, in the 1:1 ratio of H_2O and CH_3CN solvent mixtures, 2,6-dimethoxyphenol (**1a**) provided *para-para* coupling biphenol **4b** in 81% yield. It is intereting to note that the 2,6-dimethoxyphenol (**1a**) provides unsymmetrical *meta*, *para* C-H coupling product **2a** in CF_3COOH solvent. Whereas, in 1:1 ratio of H_2O and CH_3CN solvent mixtures, the same substrate provided the symmetrical *para*, *para* coupling product **4b**.

It is surprising to note the different type of reactivity and coupling product was observed in the oxidative coupling of *ortho* substituted phenols with $K_2S_2O_8$ at 80 °C in 1:1 mixture of water and CH_3CN solvents. When 2-methylphenol (**1o**) was treated with $K_2S_2O_8$ in a 1:1 mixture of water and CH_3CN solvents, quinoid type coupling product **6a** was observed in 78% yield (Scheme 5).[9a] In a similar fashion, 2-*iso*propylphenol (**1p**), 2-phenylphenol (**1q**) and 2-benzylphenol (**1r**) provided quinoid coupling products **6b-d** in 75%, 60% and 51% yields, respectively. The reaction was further examined with *meta* substituted phenols such as *meta* Me and OMe substituted phenols. These substrates were not compatible for the reaction and no expected coupling product was observed. However, 2,5-dimethylphenol (**1s**) and 2-methyl-4-hydroxy phenol (**1t**) provided quinone derivatives **6e** and **6f** in good yields.



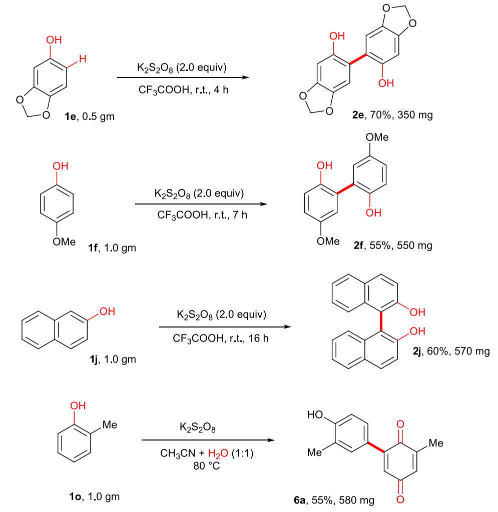
Scheme 5 Synthesis of substituted benzoquinones



Scheme 6 Synthesis of substituted naphthoquinones

The coupling reaction was also examined with substituted 2-naphthols **1j-l** (Scheme 6). 2-Naphthol (**1j**) and 2,7-dihydroxy naphthalene (**1l**) underwent oxidative coupling reaction under similar reaction conditions providing quinoid coupling products **6g** and **6h** in 80% and 73% yields, respectively (Scheme 6). Product **6g** undergoes condensation with benzene-1,2-diamine (**7**) providing biologicaly active phenazine derivative **8** in 69% yield.[9b] It is noteworthy to mention that the 1,4-naphthquinone (**6h**) was observed in 1-naphthol (**1u**) substrate under similar recation conditions.

A gram scale synthesis of biphenols and binaphthols was demonstrated in Scheme 7. The homocoupling of 500 mg of sesamol (**1e**), 1.0 gm of 4-methoxy phenol (**1f**) and 1.0 gm of 2-naphthol (**1j**) with $K_2S_2O_8$ under ambient conditions provided the expected products **2e**, **2f** and **2j** in 70%, 55% and 60% yields, respectively. Similarly, 1.0 gm of 2-methylphenol (**1o**) reacted with $K_2S_2O_8$ in a 1:1 mixture of water and CH_3CN solvents providing product **6a** in 55% yield.



Scheme 7 A gram scale synthesis of biphenols

In conclusion, we have demonstrated an efficient synthesis of symmetrical and unsymmetrical biphenols and binaphthols by using green and easily available $K_2S_2O_8$ as an oxidant. In the reaction, *ortho-ortho*, *ortho-meta*, *meta-para* and *para-para* coupling products were observed in the homocoupling of phenols with different solvents. Meanwhile, the preparation of unsymmetrical quinoid from 2-substituted phenols and 2-naphthols was described. A gram scale synthesis of biphenols and binaphthols was also demonstrated.

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Notes and references

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† Electronic Supplementary Information (ESI) available: Detailed experimental procedures and spectroscopic data. See DOI: 10.1039/b000000x/

1 Selected reviews: (a) J. Hassan, M. Sévignon, C. Gozzi, E. Schulz, M. Lemaire, *Chem. Rev.*, 2002, **102**, 1359; (b) Y. Chen, S. Yekta, A. K. Yudin, *Chem. Rev.*, 2003, **103**, 3155; (c) K. C. Nicolaou, P. G. Bulger, D. Sarlah, *Angew. Chem., Int. Ed.*, 2005, **44**, 4442; (d) G. Bringmann, A. J. Mortimer, P. A. Keller, M. J. Gresser, J. Garner, M. Breuning, *Angew. Chem.,Int. Ed.*, 2005, **44**, 5384; (e) G. P.

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McGlacken, L. M. Bateman, *Chem. Soc. Rev*., 2009, **38**, 2447; (f) S. E. Allen, R. R. Walvoord, R. Padilla-Salians, M. C. Kozlowski, *Chem. Rev*. 2013, **113**, 6234; (g) D. Parmar, E. Sugiono, S. Raja, M. Rueping, *Chem. Rev*., 2014, **114**, 9047.

2 (a) H. Aldemir, R. Richarz, T. A. M Gulder, *Angew. Chem. Int. Ed.*, 2014, **53**, 8286; (b) E. Dagne, W. Steglich, *Phytochemistry*, 1984, **23**, 1729; (c) M. H. Zenk, R. Geeardy, R. Stadler, *J. Chem. Soc. Chem. Commun*., 1989, 1725; (d) R. Gerardy, M. H. Zenk, *Phytochemistry*, 1992, **32,** 79; (e) S. Pal, J. M. Bollag, P. M. Huang, *Soil Biol, Biochem*., 1994, **26**, 813; (f) N. Ikezawa, K. Iwasa, F. Sato, *J. Biol. Chem.*, 2008, **283**, 8810; (g) P. F. X. Kraus, T. M. Kutchan, *Proc. Natl. Acad. Sci. USA* 1995, **92**, 2017; (h) L.B. Davin, H. B. Wang, A. L. Crowell, D. L. Bedgar, D. M. Martin, S. Sarkanen, N. G. Lewis, *Science*, 1997, **275**, 362; (i) K. Freudenberg, *Nature.* 1959, **183**, 1152.

3 Selected papers: (a) M. J. S. Dewar, T. Nakaya, *J. Am. Chem. Soc*., 1968, **90**, 7134; (b) K. Yamamoto, H. Fukushima, Y. Okomoto, K. Hatada, M. Nakazaki, *J. Chem. Soc. Chem. Commun.*, 1981, **46**, 2547; (c) K. Ding, Y. Wang, L. Zhang, Y. Wu, *Tetrahedron*, 1996, **52**, 1005; (d) J. Doussot, A. Guy, C. Ferroud, *Tetrahedron Lett*., 2002, **41**, 2545; (e) G. Bringmann, T. Gulder, T. M. Gulder, M. Breuning, *Chem. Rev*., 2011, **111**, 563; (f) M. Grzybowski, K. Skonieczny, H. Butenschon, D. T. Gryko, *Angew. Chem. Int. Ed*., 2013, **52**, 9900.

4 Selected papers: (a) J. A. Ashenhurst, *Chem. Soc. Rev*., 2010, **39**, 540; (b) A. E. Wendllandt, A. M. Suess, S. S. Stahl, *Angew. Chem. Int. Ed*., 2011, **50**, 11062; (c) M. Matsushita, K. Kamata, K. Yamaguchi, N. *J.* Mizuno, *Am. Chem. Soc.*, 2005, **127**, 6632; (d) A. S. Hay, H. S. blanchard, G. F. Endres, Eustance, *J. Am. Chem. Soc*. 1959, **81**, 6335; (e) Q. Jiang, W. Sheng, M. Tian, J. Tang, C. Guo, *Eur. J. Org. Chem*. 2013, 1861; (f) P. J. Wallis, K. J. Booth, A. F. Patti, J. L. Scott, *Green Chem.* 2006, **8**, 333; (g) K. V. N. Esguerra, Y. Fall, L. Petitjean, J.-P. Lumb, *J. Am. Chem. Soc.*, 2014, **136**, 7662; (h) D.-R. Hwang, C.-P. Chen, B.-J. Uang, *Chem. Commun*., 1999, 1207; (i) E. Gaster, Y. Vainer, A. Regev, S. Narute, K. Sudheendran, A. Werbeloff, H. Shalit, D. Pappo, *Angew. Chem. Int. Ed*., 2015, **54**, 4198; (j) Y. E. Lee, T. Cao, C. Torruellas, M. C. Kozlowski, *J. Am. Chem. Soc*., 2014, **136**, 6782; (k) A. Libman, H. Shalit, Y. Vainer, S. Narute, S. Kozuch, D. Pappo, *J. Am. Chem. Soc*. 2015, **137**, 11453. (f) S. Narute, R. Parnes, F. D. Toste,D. Pappo, *J. Am. Chem. Soc.*,2016, *DOI: 10.1021/jacs.6b11198*; (g). Q. Jiang, W. Sheng, M. Tian, J. Tang, C. Guo, *Eur. J. Org. Chem*., 2013, 1861; (m) Z. Maeno, M. Okao, T. Mitsudome, T. Mizugaki, K. Jitsukawaa, K. Kaneda, *RSC Adv*., 2013, **3,** 9662.

5 Selected papers: (a) B. Su, L. Li, Y. Hu, Y. Liu, Q. Wang, *Adv. Synth. Catal*., 2012, **354**, 383; (b) T. Dohi, A. Maruyama, M. Yoshimura, K. MorimotoH. , Tohma, Y. Kita, *Angew. Chem. Int. Ed*., 2005, **44**, 6193, (c) L. Zhai, R. Shukla, S. H. Wadumethrige, R. Rathore, *J. Org. Chem*., 2010, **75**, 4748; (d) K. Morimoto, K. Sakamoto, Y. Ohnishi, T. Miyamoto, M. Ito, T. Dohi Y. , Kita, *Chem. Eur. J*., 2013, **19,** 8726; (e) R. Neelamegam, M. T. Palatnik, J. Fraser-Rini, M. Slifstein, A. Abi-Dargham, B. Easwaramoorthy, *Tetrahedron Lett*., 2010, **51**, 2497; (f) K. Morimoto, K. Sakamoto, T. Ohshika, T. Dohi, Y. Kita, *Angew. Chem. Int. Ed*., 2016, **55,** 3652. (g) G. Jacquemot, M.-A. Ménard; C. L. Homme and S. Canesi, *Chem. Sci*. **2013**, *4*, 1287; (h) K. C. Guerard, C. Chapelle, M.-A. Giroux, C. Sabot, M.-A. Beaulieu, N. Achache and S. Canesi, *Org. Lett*. **2009**, *11*, 4756; (i) G. Jacquemot and S. Canesi, S. *J. Org. Chem*. 2012, **77**, 7588; (j) A. P. Antonchick, R. Samanta, K. Kulikov and J. Lategahn, *Angew. Chem. Int. Ed.* **2011**, *50*, 8605; (k) S. Manna, P. O. Serebrennikova, I. A. Utepova, A. P. Antonchick and O. N. Chupakhin, *Org. Lett*. **2015**, *17*, 4588; (l) Kazi, I.; Guha, S.; Sekar, S. *Org. Lett*. **2017**, *19*, 1244. (m) Kotha, S. S.; Sekar, G. Tetrahedron. Lett. 2015, 56, 6323. (n) Guha, S.; Rajeshkumar, S.; Surya, S. K; Sekar, S. *Org. Lett.* **2015**, *17*, 406.

6 Selected papers: (a) A. Kirste, G. Schnakenburg, S. R. Waldvogel,. *Org. Lett*., 2011**,** **13**, 3126; (b) D. Mirk, A. Willner, R. Frohlich, S. R. Waldvogel, *Adv. Synth. Catal*., 2004, **346,** 675; (c) A. Kirste, M. Nieger, M. I. Malkowsky, F. Stecker, A. Fischer, S. R. Waldvogel, *Chem. Eur. J*., 2009, **15**, 2273; (d) I. M. Malkowsky, U. Griesbach, H. Putter, S. R. Waldvogel, *Eur. J. Org. Chem*., 2006, 4569; (e) B. Elsler, A. Wiebe, D. Schollmeyer, K. M. Dyballa, R. Franke, S. R. Waldvogel, *Chem. Eur. J*., 2015, **21,** 12321; (f) H. J Schafer,. *ChemCatChem*., 2014, **6,** 2792; (a) A. Kirste, G. Schnakenburg, F. Stecker, A. Fischer, S. R. Waldvogel, *Angew. Chem. Int. Ed*., 2010, **49**, 971; (b) A. Kirste, B. Elsler, G. Schnakenburg, S R. Waldvogel, *J. Am. Chem. Soc*., 2012, **134**, 3571; (c) B. Elsler, D. Schollmeyer, K. M. Dyballa, R. Franke, S. R. Waldvogel, *Chem. Eur. J.*, 2015, **21**, 12321; (d) B. Elsler, B. Schollmeyer, K. M. Dyballa, R. Franke, S. R. Waldvogel, *Angew. Chem. Int. Ed*., 2014, **53**, 5210; (e) A. Wiebe, . D. Schollmeyer, K. M. Dyballa, R. Franke, S. R. Waldvogel, *Angew. Chem. Int. Ed*., 2016, **55**, 11801; (f) A. Kirste, G. Schnakenburg, S. R. Waldvogel, *Org. Lett*., 2011**,** **13**, 3126; (g) I. M. Malkowsky, U. Griesbach, H. Putter, S. R. Waldvogel, *Eur. J. Org. Chem*., 2006, 4569. (h) Mirk, A. Willner, R. Frohlich, S. R. Waldvogel, *Adv. Synth. Catal*., 2004, **346**, 675; (i) S. Lips, A. Wiebe, B. Elsler, D. Schollmeyer, K. M. Dyballa, R. Franke, S. R. Waldvogel, *Angew. Chem. Int. Ed*., 2016, **55**, 10872.

7 (a) N. Y. More, M. Jeganmohan, *Org. Lett*., 2015, **17**, 3042. (b) N. Y. More, M. Jeganmohan, *Org. Lett*., 2014, **16**, 804; (c) N. Y. More, M Jeganmohan, *Chem. Eur. J*., 2015, **21**, 1337.

8 (a) W. C. Vasudeva, *J. Chem. Soc.*, *Perkin II*, 1975, 697; (b) T. A. Gadosy, D. Shukla, L. J. Johnston, *J. Phys. Chem. A.*, 1999, **103**, 8834; (c) R. Joshi, S. Naumov, S. Kapoor, T. Mukherjee, R. Hermann, O. Brede, *J. Phys. Org. Chem.*, 2004, **17,** 665; (e) S. Sankararaman, W. A. Haney, J. K. Kochi, *J. Am. Chem. Soc*., 1987, **109,** 7824; (f) Y. Kita, H. Tohma, K. Hatanaka, T. Takada, S. Fujata, S. Mitoh, H. Sakurai, S. Oka, *J. Am. Chem. Soc*., 1994, **116**, 3684. (g) D. Collado, E. Perez-Inestrosa, R. Suaua, J. T. L. Navarrete,. *Tetrahedron.* 2006**, 62**, 2927.

9 (a) Y. Takizawa, T. Munakata, Y. Iwasa, T. Suzuki, and T. Mitsuhashi, *J. Org. Chem*. 1985, **50**, 4383; (b) H. Hussain, S. Specht, S. R. Sarite, M. Saeftel, A. Hoerauf, B. Schulz, K. Krohn, *J. Med. Chem*., 2011, **54**, 4913.

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