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Palladium-catalyzed dehydrogenation of dihydro-heterocycles using isoprene as the hydrogen acceptors without oxidants

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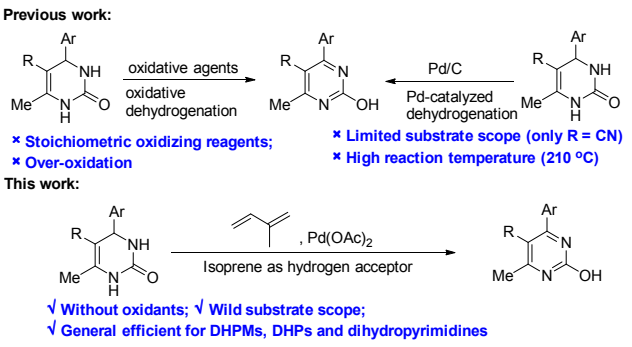
An efficient and general method for the Pd-catalyzed dehydrogenative aromatization of dihydro-heteroatom compounds without external O_2 and H_2 is first described. The protocol firstly uses isoprene as a hydrogen acceptor. Various dihydro-heterocycles including dihydropyrimidinones, dihydropyrimidines and dihydropyridines can be dehydrogenated to produce the corresponding aromatic heterocyclic compounds.

Oxidation anddehydrogenation reactions are one of the most common chemical transformations in organic chemistry, which provide extensively varied methods for the construction of organic molecules.[1]These transformations were also widely used to form aromatic structures,[2] which are usually valuable chemicals with pharmaceutical and other functional activities.[3]Developing practical and sustainable catalytic methods for selective oxidation and dehydrogenation reactions is an important challenge. Therefore, the search for aromatization through oxidative dehydrogenation to prepare substituted hetero aromatic molecules has been the focus of much attention.[4-6] For example, the oxidative dehydrogenation of various substrates including heterocycles is emerging as a versatile strategy to achieve (hetero)aromatics and phenols,[7] which is designed to be a complementary route for the convenient synthesis of the aromatic structures.

3,4-Dihydropyrimidine (DHPM) derivatives as well as their analoguepyridine derivatives were proved with a wide range of biological activity and utilizations in diversity- and target-oriented synthesis.[8]The transformations of the DHPMs and 1,4-dihydropyridines (DHPs) ring to the corresponding 2-hydroxylpyrimidines and pyridines have becoming a class of important reactions for the synthesis of the N-heterocyclic compounds because DHPMs and DHPs can be easily prepared from Biginelli and Hantzsch reactions.[9]



Scheme 1. Dehydrogenative aromatization of DHPMs.

There are several reports for the oxidative aromatization of Hantzsch type dihydropyridines[10] and DHPM derivatives,[11]using an excess of oxidizing reagents such as HNO_3, DDQ, CAN, $PhI(OAc)_2$, I_2, TBHP, NHPI, $Co(OAc)_2Zr(NO_3)_4$, and others (Scheme 1).Photochemical example for dehydrogenation of DHPMs were also reported.[12]Although these methods are approaches for the oxidative aromatization of these heterocycles, they generally require stoichiometric oxidizing reagents or hydrogen acceptors, and/or harsh reaction conditions. Moreover, the selective oxidation of the dihydropyrimidine ring is troublesome due to the sensitivity of the C6-methyl group to oxidants giving rise to byproducts and these reactions limited substrate scope.

Alternatively, transition metals-catalyzed dehydrogenation has emerged as a promising alternative to oxidizing reagents-based methods, and Pd-C/AcOH-promoted protocols for the

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oxidative aromatization of DHPs and DHPMs have been realized (Scheme 1).[13]Yamamoto et al have examined the Pd/C-, $RuCl_3$- and $Pd(OAc)_2$-catalyzed oxidative dehydrogenation of DHPM and dihydropyrimidines to give the aromatic products. High conversions and product yields were obtained with these process. However, the substrates possessing an ester group in the DHPM ring are not compatible with Pd/C catalyzed oxidation methods. Moreover, they suffer some drawbacks, including the requirement rigorous conditions (210 °Chigh reaction temperature in Ph_2O).

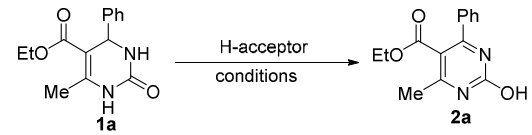
So far, no general and practical synthetic procedure for both of DHPs and DHPMs has been disclosed, though several different methods for the dehydrogenation of specific compounds have been developed. Thus, achieving a versatile and general method for dehydrogenation of DHPs and DHPMs, remains a key challenge.

Alkenes have been used as hydrogen-acceptor in the dehydrogenation (oxidation) of several organic compounds. For example, 1,2,3,4-tetrahydroisoquinoline was transformed into isoquinoline catalyzed by Pd/C under an ethylene atmosphere. Hayashi *et al.*[14]developed a serious of methods for the Pd-catalyzed dehydrogenation of benzylic and allylic alcohols into carbonyl compounds in the presence of vinyl acetate or under the ethylene atmosphere. More recently, Mizun*et al.*[15] reported a gold–palladium alloy catalyzed dehydrogenated aromatization of cyclohexanones using styrene as a hydrogen-acceptor to give N-substituted anilines.

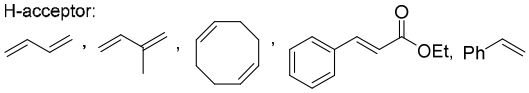
Herein, we report an oxidant-free Pd-catalyzed dehydrogenation of heteroatom compounds to their corresponding aromatic products (Scheme 1). It is the first time that a diene (2-methyl-1,3-butadiene) can act as an effective hydrogen-acceptor for the dehydrogenative transformation. The present Pd-catalyzed system in the presence of 2-methyl-1,3-butadiene is applicable to a wide range of substituted dihydro-heterocyclesincluding 3,4-dihydropyrimidine-2(1H)-one, 1,4-dihydropyrimidines and 1,4-dihydropyridines.

In contrast to the quantitative dehydrogenation of DPHs, the dehydrogenation of DHPMs was found to be more difficult because of its highly stable structure.[11f]Therefore, we initially began examination of the dehydrogenative aromatization of DHPM **1a** using 2.5 mol % $Pd(OAc)_2$ as a catalyst and 5 mol % DPEphos in the presence of buta-1,3-diene **Ha** as hydrogen-acceptor and K_2CO_3 as a base under Ar atmosphere (Table 1). The reaction proceeded and produced the desired aromatization product **2a** with a 27% yield (entry 1). Thus, buta-1,3-diene wasnot suitable for the present system. When utilizing isoprene **Hb** as the hydrogen acceptor under an Ar atmosphere (1 atm), the desired pyrimidine **2a** was selectively obtained with a yield of 67% without the formationof the undesired products (Table 1, entry 2). A range of hydrogen-acceptor, including isoprene **Hb**,cycloocta-1,5-diene **Hc**, ethyl cinnamate **Hd**, and styrene **He** were then evaluated (entries 3–5). While **Hd** and **He** were also effective, but with a low yield of **2a** (36% and 40%, entries 4 and 5). However, no product was detected using **Hc** (entry 3). The metal-catalyst also plays an important role in this reaction; $Pd(OAc)_2$ was more effective than other tested catalysts such as Fe, Ni and Cu-catalysts (entries 6-9), meanwhile $Cu(OAc)_2$ also gave an acceptable result with 56% yield of **2a** (entry 8). Evaluation of various ligands led to the observation that a good yield of **2a** (67% and 68%) was obtained when DPEphos and Xphos were used, respectively (entry 2 vs entry 10).

Table 1 Optimization of the reaction conditions for dehydrogenation[a]



H-acceptor:



Ha **Hb** **Hc** **Hd** **He**

entry	catal.	ligand	H-acceptor	base	**2a** Yield/%
1	$Pd(OAc)_2$	DPE-phos	**Ha**	K_2CO_3	27
2	$Pd(OAc)_2$	DPE-phos	**Hb**	K_2CO_3	67
3	$Pd(OAc)_2$	DPE-phos	**Hc**	K_2CO_3	n.r
4	$Pd(OAc)_2$	DPE-phos	**Hd**	K_2CO_3	36
5	$Pd(OAc)_2$	DPE-phos	**He**	K_2CO_3	40
6	$FeCl_3$	DPE-phos	**Hb**	K_2CO_3	12
7	$Ni(acac)_2$	DPE-phos	**Hb**	K_2CO_3	n.r
8	$CuSO_4$	DPE-phos	**Hb**	K_2CO_3	45
9	$Cu(OAc)_2$	DPE-phos	**Hb**	K_2CO_3	56
10	$Pd(OAc)_2$	Xphos	**Hb**	K_2CO_3	69
11	$Pd(OAc)_2$	dppe	**Hb**	K_2CO_3	61
12	$Pd(OAc)_2$	1,10-Phen	**Hb**	K_2CO_3	42
13	$Pd(OAc)_2$	DPE-phos	**Hb**	K_2CO_3	53,[b] 40,[c]n.r.,[d]trace[e]
14	$Pd(OAc)_2$	DPE-phos	**Hb**	Cs_2CO_3	72
15	$Pd(OAc)_2$	DPE-phos	**Hb**	Et_3N	51
16	$Pd(OAc)_2$	DPE-phos	**Hb**	Cs_2CO_3	15[f]
17	$Pd(OAc)_2$	DPE-phos	-	Cs_2CO_3	NR
18	$Pd(OAc)_2$	DPE-phos	**Hb**	-	54

[a]Conditions: **1a** (0.25 mmol), H-acceptor (2 eq.),catalyst (2.5mol%), ligand (5mol%), base (0.5 eq.),toluene (3 mL), 120°C, Ar atmosphere, 36 h.[b-e]Reaction was carried out in xylene, dioxane, DMSO and DMF, respectively.[f]Reaction was carried out under air conditions.

DPE-phos=bis(2-diphenylphosphinophenyl)ether;Xphos=2-(dicyclohexylphosphino)-2',4',6'-triisopropylbip;dppe=1,2-bis(diphenylphosphino)ethane;1,10-Phen=1,10-phenanthroline.

Moreover, the effect of solvent was investigated, and toluene was better than xylene, 1,4-dioxane and DMF (entry 13). When Cs_2CO_3 was used as the base, a higher yield of **2a** (72%) was observed (entries 14-15). When the reaction was carried out under air conditions it gave a lower yield of **2a** (entry 16).As expected no reaction occurred without addition of H-acceptor and the starting materials were recovered (entry 17).The desired product **2a** was also afforded with moderate yield(54%) without Cs_2CO_3 (entry 18).It should be noted thatin

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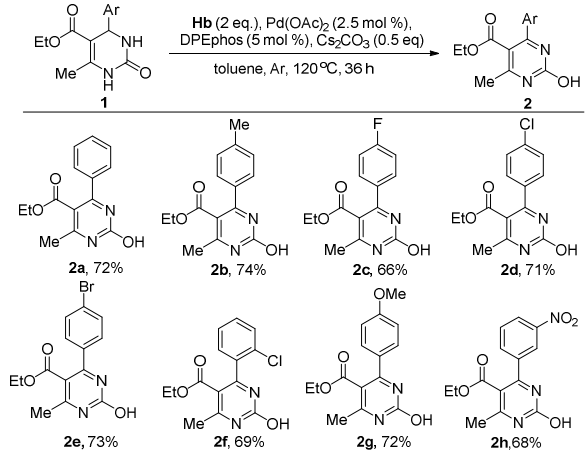
cases of low yield of product, the starting materials were recovered with trace amount of by-products.

Using these optimized conditions, we next varied the DHPMs**1** in the dehydrogenation reaction (Scheme 2). The reaction exhibited an excellent profile, tolerating a wide range of functional groups. DHPMs substituted with electron-donating (**2b**, **2g**) and electron-withdrawing (**2c-2e**) groups were well tolerated. Steric hindrance at the *ortho*-position was also tolerated (**2f**).Notably, few reports on dehydrogenation of DHPM has given a glace on the NO_2 group substituted DHPM.[11]Additionally, nitro-group substituted DHPM produced product **2h** with a high yield of 76%.

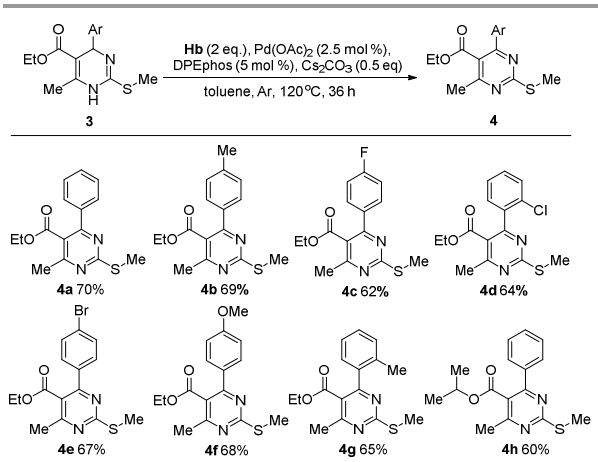


Scheme 2. Scope of DHPM for dehydrogenation

To test the scalability of the current method, the reaction of **1a** (5mmol, 1.3 g) and isoprene **Hb** (10 mmol, 1.04 g) in the presence of Cs_2CO_3 (2.5 mmol, 0.68 g) was carried out on a gram scale under the optimal conditions, and the product **2a** was isolated in 68% yield.

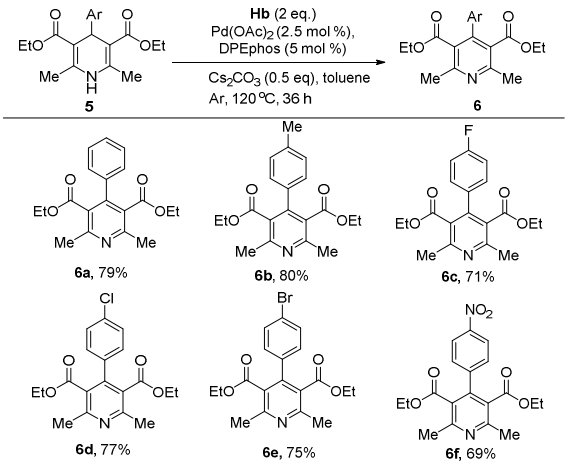
We then explored whether the DHPMs can be replaced by the 1,4-dihydropyrimidines and tested 2-(alkylthio)-1,4-dihydropyrimidines **3** as substrates (Scheme 3). Thioethers present in many biologically active compounds and they are widely used as building blocks in organic synthesis and receive considerable attention.[16] Pleasingly, **3a** was dehydrogenated under the optimized conditions to give the targeted aromatization **4a** in 70%. The Me-, F-, and Br-substituted 1,4-dihydropyrimidines transformed into the primidine derivatives (**4b**, **4c**, and **4e**) in good yields. Steric hindrance (Cl, Me) at the *ortho*-position was also tolerated to give the products (**4d**, **4g**). Along these lines, 1,4-dihydropyrimidine containing C5-*i*Pr-substituted ester provided the desired product **4h**.

Additionally, a variety of different Hanstch esters were examined to evaluate the substrate scopeand resulted in good yields to the aromatized products **6a-6f** (Scheme 4). Generally, slightly higher yields were achieved with Hanstch ester to provide the aromatization products **6** than those of 1,4-dihydropyrimidines.Impact from the substituted groups was slight and fluoro- and nitro-groups were also well tolerated to achieve good yields of products **6c** and **6f**, meanwhile slightly lower yields were observed.



Scheme 3. Scope of thioethersfor dehydrogenation

On the basis of the data described above and the previous work, we provided a possible mechanism shown in Scheme 5. Palladium was intrinsically effective for the present dehydrogenative aromatization. Pd^{II} is first reduced to Pd^0 by ligand DPE-Phos, which then reacts with DHPM **1** to generate a Pd-DHPM species **A** by deprotonative coordination with the assistance of base Cs_2CO_3. Subsequently, species **A** coordinate with N-atom and β-H elimination to give the Pd-H species **B**.[17] The Pd-H species **B** then undergo deprotonation in the presence of diene **Hb** affording 1,2-dihydropyrimidine **C**, followed by theisomeric aromatization to produce the correspondingpyrimidines **2**. In the dehydrogenationstep, isoprene could act as an effective hydrogen acceptor to produce the desired 1,2-intermediatesdihydropyrimidines **C**. The reaction process was monitored by ^1H NMR experiments, and two new were appeared around 1.30 and 1.60 ppm due to the shift of alkane after reacting for 12 h and 24 h along with the disappearing of the resonances at 5.50 and 6.80 ppm belonged to isoprene. These results indicate that isoprene was transformed into isoprane or isopentene.



Scheme 4. Scope of Hanstch esters for dehydrogenation

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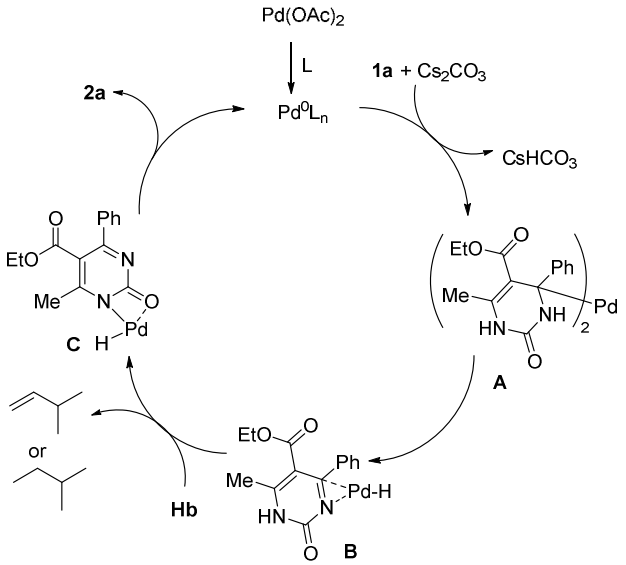
Conclusions

In summary,we have developed an efficientandwidely applicable dehydrogenation of dihydro-heteocycles to the corresponding aromatic heterocyles. Catalyzed by $Pd(OAc)_2$ in the presence of isoprene as the hydrogen acceptor, various kinds of structurally diversely aromatized pyrimidine and pyridine derivatives can be obtained, which can be used as organic building blocks or as important heterocyclic ring in valuable drug candidates.



Scheme 5. Proposed mechanistic pathway of palladium-catalyzed dehydrogenation of DHPMs

Acknowledgements

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Notes and references

1 For selected reviews, see: (a) *ComprehensiVe Organic Syntheses*, B. M. Trost and I. Fleming, Eds; Pergamon: Oxford, UK, 1992, **7**, 395-395. (b) W. J. Mijs and C. R. H. I. De Jonge, Eds; Plenium Press: New York, *Organic Syntheses by Oxidation with Metal Compounds*, 1986, **19**, 569-631.

2 For selected examples, see: (a) N. Nakamichi, Y. Kawashita and M. Hayashi, *Synthesis*, 2004, **7**, 1015-1020. (b) N. Nakamichi, H. Kawabata and M. Hayashi, *J. Org. Chem.,* 2003, **68**, 8272-8273. (c) Y. Kawashita, N. Nakamichi, H. Kawabata and M. Hayashi, *Org. Lett.,* 2003, **5**, 3713-3715.

3 (a) U. S. Schubert and C. Eschbaumer, *Angew. Chem. Int. Ed.,* 2002, **41**, 2892-2926. (b) G. C. Fu, *Acc. Chem. Res.,* 2004, **37**, 542-547. (c) H. Hofmeier and U. S. Schubert, *Chem. Commun.,* 2005, **21**, 2423-2432. (d) N.-G. Kang, M. Changez and J.-S. Lee, *Macromolecules*, 2007, **40**, 8553-8559. (e) T. Šmejkal and B. Breit, *Angew. Chem. Int. Ed.,* 2008, **47**, 311-315. (f) S. Lin and X. Lu, *Org. Lett.,*2010, **12**, 2536-2539. (g) R. Makiura, S. Motoyama, Y. Umemura, H. Yamanaka, O. Sakata and H. Kitagawa, *Nat. Mater.,* 2010, **9**, 565-571.

4 (a) J. A. Varela and C. Saá, *Chem. Rev.,* 2003, **103**, 3787-3801. (b) I. Nakamura and Y. Yamamoto, *Chem. Rev*., 2004, **104**, 2127-2198. (c) G. Domínguez and J. Pérez-Castells, *Chem. Soc. Rev.,* 2011, **40**, 3430-3444.

5 For selected examples, see: (a) L. T. Pilarski, N. Selander, D. Böse, and K. Szabó, *J. Org. Lett.,* 2009, **11**, 5518-5521. (b) Y. Izawa, D. Pun and S. S. Stahl, *Science*, 2011, **333**, 209-213. (c) Y. Izawa, C. Zheng and S. S. Stahl, *Angew. Chem. Int. Ed.,***2013**, *52*, 3672-3675. (d) D. Pun, T. Diao and S. S. Stahl, *J. Am. Chem. Soc.,* 2013, **135**, 8213-8221. (e) T. Imahori, T. Tokuda, T. Taguchi and H. Takahata, *Org. Lett.,* 2012, **14**, 1172-1175.

6 (a) D. Kim, M. Min and S. Hong, *Chem. Commun.,* 2013, **49**, 4021-4023. (b) S. Chen, Y. Liao, F. Zhao, H. Qi, S. Liu and G.-J. Deng, *Org. Lett.,* 2014, **16**, 1618-1621. (c) Y. Liao, Y. Peng, H. Qi, G.-J. Deng, H. Gong and C.-J. Li, *Chem. Commun.,* 2015, **51**, 1031-1034. (d) M.-O. Simon, S. A. Girard and C.-J. Li, *Angew. Chem. Int. Ed.,* 2012, **51**, 7537-7540. (e) M. Sutter, N. Sotto, Y. Raoul, E. Métay and M. Lemaire, *Green Chem.,* 2013, **15**, 347-352. (f) S. A. Girard, X. Hu, T. Knauber, F. Zhou, M.-O. Simon, G.-J. Deng and C.-J. Li, *Org. Lett.,* 2012, **14**, 5606-5609. (g) A. Hajra, Y. Wei, N. Yoshikai, *Org. Lett.,* 2012, **14**, 5488-5491. (h) Y. Xie, S. Liu, Y. Liu, Y. Wen and G.-J. Deng, *Org. Lett.,* 2012, **14**, 1692-1695. (i) W. P. Hong, A. V. Iosub and S. S. Stahl, *J. Am. Chem. Soc.,* 2013, **135**, 13664-13667.

7 For selected reviews on the dehydrogenation, see: (a) G. E. Dobereiner and R. H. Crabtree, *Chem. Rev.,* 2010, **110**, 681-703. (b) J. Choi, A. H. R. MacArthur, M. Brookhart and A. S. Goldman, *Chem. Rev.,* 2011, **111**, 1761-1779. Selected examples on the heterocyclesoxidative dehydrogenation, see: (c) M. Gupta, C. Hagen, R. J. Flesher, W. C. Kaska and C. M. Jensen, *Chem. Commun.,* 1996, 2083-2084. (d) S. Aiki, Y. Kijima, J. Kuwabara, A. Taketoshi, T.-a. Koizumi, S. Akine and T. Kanbara, *ACS Catal.,* 2013, **3**, 812–816. (e) K. C. Nicolaou, C. J. N. Mathison and T. Montagnon, *J. Am. Chem. Soc.,* 2004, **126**, 5192-5201. (f) S. Haneda, A. Okui, C. Ueba and M. Hayashi, *Tetrahedron,* 2007, **63**, 2414-2417. (g) Y. Huang, X. Zu, F. Wu, J. Xu, X. Wu and H. Yao, *Tetrahedron,* 2012, **68**, 3123-3128.

8 For selected reviews, see: (a) C. O.Kappe, *Tetrahedron Lett.* 1993, **49**, 6937-6963. (b) C. O. Kappe and A. Stadler, *Org. React.,* 2004, **63**, 1-116. (c) C. O. Kappe, *Eur. J. Med. Chem.,* 2000, **35**, 1043–1052. (d) C. O. Kappe,*Acc. Chem. Res.,* 2000, **33**, 879–888. (e) Z.-J. Quan, Z. Zhang, Y.-X. Da, X.-C. Wang, *Chin. J. Org. Chem.,* 2009, **29**, 876-883.

9 (a) X.-C. Wang, G.-J. Yang, Z.-J. Quan, P.-Y. Ji, J.-L. Liang and R.-G. Ren, *Synlett*, 2010, **11**, 1657–1660. (b) Z.-J. Quan, W.-H. Hu, X-D. Jia, Z. Zhang, Y.-X. Da and X.-C. Wang, *Adv. Synth. Catal*., 2012, **354**, 2939-2948; (c) Z.-J. Quan, F.-Q. Jing, Z. Zhang, Y.-X. Da and X.-C. Wang, *Eur. J. Org. Chem.,* 2013, **31**, 7175-7183. (d) Z.-F. Yan, Z.-J. Quan, Y.-X. Da, Z. Zhang and X.-C. Wang, *Chem. Commun.,* 2014, **50**, 13555-13558.

10 (a) P. Prakash, E. Gravel, H. Li, F. Miserque, A. Habert, M. den Hertog, W. L. Ling, I. N. N. Namboothiri and E. Doris, *Catal. Sci. Technol.*, 2016, **6**, 6476-6479. (b) C-B. Bai, N.-X. Wang, Y.-J. Wang, X.-W. Lan, Y. Xing and J.-L. Wen, *RSC Adv*., 2015, **5**, 100531-100534. And references cited herein.

11 (a) M. Watanabe, H. Koike, T. Ishiba, T. Okada, S. Seo and Hirai, K. *Bioorg. Med. Chem.,* 1997, **5**, 437-444.(b) J. J. Eynde, N. Audiart, V. Canonne, S. Michel, Y. V. Haverbekeand C. O. Kappe, *Heterocycles*, 1997, **45**, 1967-1978. (c) A. Puchala, F. Belaj, J. Bergman and C. O. Kappe, *J. Heterocycl. Chem.,* 2001, **38**, 1345-1352. (d) T.-P. Nguyen-Huu and S. Jeong-Hun, *Tetrahedron,* 2014,**70**, 7929-7935. (e) K. Yamamoto, Y. G. Chen and F. G. Buono, *Org. Lett*., 2005, **7**, 4673-4676. (f) P. Shanmugam and P. T. Perumal, *Tetrahedron,* 2006, **62**, 9726-9734. (g) N. N. Karade, S. V. Gampawar, J. M. Kondre and G.

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DOI: 10.1039/C6CY02038K

B. Tiwari, *Tetrahedron Lett*., 2008, **49**, 6698-6700. (h) A. R. Gholap, K. S. Toti, F. Shirazi, M. V. Deshpande and K. V. Srinivasan, *Tetrahedron*,2008, **64**, 10214–10223. (i) B. Han, R.-F. Han, Y.-W. Ren, X.-Y. Duan, Y.-C. Xu and W. Zhang, *Tetrahedron,* 2011, **67**, 5615-5620.

12 (a) H. R. Memarian and A. Farhadi, *Monatsh. Chem.,* 2009, **140**, 1217-1220. (b) H. R. Memarian, A. Farhadi, H. Sabzyan and M. Soleymani, *J. Photochem. Photobiol. A: Chem*., 2010, **209**, 95-103. (c) Q. Liu, Y.-N. Li, H.-H. Zhang, B. Chen, C.-H. Tung and L.-Z. Wu, *J. Org. Chem.,* 2011, **76**, 1444-1447.

13 (a) C. O. Kappe and P.Roschger, *J. Heterocycl. Chem.,* 1989, **26**, 1555-1560. (b) M. Hayashi, K. Yamada, S. Nakayama, H. Hayashi and S. Yamazaki, *Green Chem.,* 2000, **2**, 257-260. (c) N. Nakamichi, Y. Kawashita and M. Hayashi, *Org. Lett*., 2002, **4**, 3955-3957.

14 (a) M. Hayashi, K. Yamada and O. Arikita, *Tetrahedron Lett*., 1999, **40**, 1171-1174. (b) M. Hayashi, K. Yamada and O. Arikita, *Tetrahedron*, 1999, **55**, 8331-8340. (c) M. Hayashi, K. Yamada and S. Nakayama, *Synthesis*, 1999, 1869-1871.

15 K. Taniguchi, X. Jin, K. Yamaguchi and Mizuno, N. *Catal. Sci. Technol.,*2016, **6**, 3929-3937.

16 I. P. Beletskaya and V. P. Ananikov, *Chem. Rev.,* 2011, **111**, 1596-1636.

17 J. N. P.van Stralen and F. M. Bickelhaupt, *Organometallics,* 2006, **25**, 4260-4268.

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Palladium-Catalyzed Dehydrogenation of Dihydro-Heterocycles Using Isoprene as the Hydrogen Acceptors without Oxidants

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