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Cross-Dehydrogenative Coupling/Annulation of Arene Carboxylic Acids and Alkenes in Water with Ruthenium(II) Catalyst and Air

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In memory of Professor Dr. Rolf Huisgen

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Abstract: A cross-dehydrogenative coupling of arene carboxylic acids with olefins is reported with ruthenium(II) catalyst employing air and water as green oxidant and solvent, respectively. It offers a robust synthesis of valuable phthalide molecules. A one-pot sequential strategy is also disclosed to access *Heck*-type products that are apparently difficult to make directly from arene carboxylic acids.

With the increasing awareness of green and sustainable chemistry principles, devising straightforward catalytic protocols to access high-value products with enriched molecular complexity is highly significant in the organic chemistry community.^[1] In this scenario, the transition-metal-catalyzed C-H bond activation concept that accounts direct utilization of otherwise inert C-H bond of organic molecules as a synthetic handle turned out very promising.^[2] It renovates the synthetic policies as a greener alternative to traditional cross-coupling reactions by avoiding the need of pre-functionalized substrates and thereby improving overall step- and atom-economy.^[3] Specifically, the cross-coupling reaction between two different C(sp²)-H bonds represents a very powerful C-C bond-forming technology as it constitutes a twofold C-H functionalization manifold.^[4] However, such oxidative cross-dehydrogenative couplings very often demand the employment of stoichiometric amounts of metal-based terminal oxidants such as Cu(II) or Ag(I) salts, generating significant amount of metallic wastes in conflict of the green chemistry principles.^[5] Employment of abundant molecular oxygen in lieu of these metal-based oxidants would be a green asset, where water is the sole byproduct.^[6] Further, a simple and cost-effective setup is expected if air can be directly engaged for the same purpose. Another critical environmental issue arises from the fact that these transformations, in general, consider a huge amount of organic solvent as compared to the other reagents and thus produce a bulk quantity of chemical waste. On the other hand, solvents play crucial roles in most of the organic transformations by controlling the reaction equilibrium and rate of the reaction.^[7] Given the environmentally benign portfolio of water, a prompt solution could be the use of water as the reaction medium.^[8] It is non-toxic, non-flammable, and naturally abundant. However, swift adoption of water as reaction medium for the transitionmetal-catalyzed C-H bond activation reactions is challenging because of the poor substrate solubility along with intrinsic sensitivity of metal catalysts and reactive organometallic

intermediates.

Aromatic carboxylic acids are shelf-stable building blocks in organic synthesis. They represent the core structure of many natural products and also acid functionality can be easily transformed into a wide range of useful functional groups. Consequently, the transition-metal-catalyzed C-H bond activation and functionalization of aromatic acids is trending^[9] and in this regime, ruthenium(II) catalysis has received considerable attention owing to its inexpensive nature in comparison to other noble metal catalysis, durability under aqueous reaction conditions, and unique reactivity profile under the assistance of weak coordination.^[9b] In 2011, Ackermann et al. first demonstrated that Ru(II)-catalyzed oxidative cross-coupling between aromatic acids and activated olefins such as acrylates and acrylonitrile smoothly took place in water (Scheme 1a).[10a] Latter, Cai et al. also showed that such reaction also proceeded in PEG-400/water mixture as reaction medium.^[10b] However, both the protocols utilized over-stoichiometric amount of $Cu(OAc)_2 H_2O$ as a terminal oxidant. Recently, Shi and Gooßen groups independently reported Ru(II)-catalyzed coupling of aromatic acids with vinyl ketones or acrylic acid in H₂O, where the protocols favoured the hydroarylation reaction mode instead of cross-dehydrogenative coupling to give C-H alkylation



products (Scheme 1a).^[11] Despite these visible advancements, to the best of our knowledge, Ru(II)-catalyzed crossdehydrogenative coupling of aromatic carboxylic acids with olefins under environmentally benign conditions that use both air as terminal oxidant and water as green solvent remains elusive. Herein, we have addressed this unmet issue through the development of regioselective cross-dehydrogenative coupling of aromatic carboxylic acids with vinyl phosphonates and concomitant annulation under inexpensive ruthenium(II) catalysis, leading to functionalized phthalides (Scheme 1b). Notably, phthalide framework is a recurrent motif in natural products.^[12] The mild reaction condition is also effective for other alkenes such as vinyl sulfone, acrylates, and acrylonitrile, while styrene can be accommodated with a modification in reaction conditions. A one-pot sequential protocol involving crossdehydrogenative annulative coupling and subsequent phthalide ring-opening has also been delineated for a formal Heck-type process (Scheme 1b).

In pursuit of greener conditions for cross-dehydrogenative coupling, we initially examined the reaction of readily available ortho-toluic acid 1a with diethyl vinyl phosphonate 2a (Table 1). To our satisfaction, coupling process proceeded smoothly with commercially available [Ru(p-cymene)Cl₂]₂ catalyst in presence of air and KOAc base in water at 100 °C and the desired product 3a was isolated in 74% yield (entry 1). Screening of other bases gave inferior yields (entries 2-5). When the loading of KOAc base was increased, yield improved gradually and complete conversion was observed for 2 equivalents of KOAc, furnishing 3a in quantitative yield (entries 6-7). A lower reaction

Table 1. Optimization of oxidative annulation reaction conditions.[a]

	$H \rightarrow P(O)(OEt)_2 = \frac{[Ru(a)]}{2a}$	p-cymene)Cl ₂] ₂ (5 mol %) base (x equiv) O (1 mL), t °C, 24 h, air	3a P(O)(OEt) ₂
Entry	Base (x equiv)	Temperature. (°C)	Yield (%) ^[b]
1	KOAc (1 equiv)	100	74
2	NaOAc (1 equiv)	100	43
3	LiOAc (1 equiv)	100	30
4	CsOAc (1 equiv)	100	62
5	KOH (1 equiv)	100	0
6	KOAc (1.5 equiv)	100	85
7	KOAc (2 equiv)	100	99
8	KOAc (2 equiv)	80	62
9	KOAc (2 equiv)	90	78
10 ^[c]	-	100	0
11 ^[d]	KOAc (2 equiv)	100	0
12 ^[e]	KOAc (2 equiv)	100	0

[a] Reaction conditions: 1a (0.2 mmol), 2a (0.24 mmol), water (1 mL) for 24 h under air. [b] Yields of isolated products are given. [c] Without KOAc. [d] Without [Ru(p-cymene)Cl2]2. [e] Under nitrogen atmosphere.

temperature led to substantial reduction in yield (entries 8-9). Control experiments showed that all components, base, catalyst, and air, are essential (entries 10-12). Reaction completely shut down in the absence of any one of them.

With this benign reaction conditions (Table 1, entry 7), the substrate generality of this protocol was surveyed (Scheme 2).



Scheme 2. Scopes of the oxidative annulation reaction of benzoic acids with vinyl phosphonates.

methodology can accommodate a wide range The of electronically and sterically diverse benzoic acid derivatives. ortho-, meta-, and para-Substituted aromatic carboxylic acids having alkoxy (3c and 3i), aryl (3d), trifluoromethyl (3e), alkyl (3f-3h) functionalities and common protecting groups, such as benzyl (3j) and methoxymethyl (MOM, 3k), delivered corresponding phthalide products in high yields. Di- and trifunctionalized benzoic acids including piperonylic acid (3I-3q) underwent a smooth transformation under the current conditions. Halogenated benzoic acids also effectively furnished products 3r-3u in good yields. Gratifyingly, presence of free hydroxyl and amine functionalities did not hamper the reaction; salicylic acid (3v), 4-hydroxybenzoic acid (3w and 3z), vanillic acid (3x), and 4-aminobenzoic acid (3y) readily rendered products in good yields (52-96%). Product 3z prepared with dimethyl vinyl phosphonate was also structurally characterized with single crystal X-ray analysis.^[13] Reactions with 1- and 2-naphthoic acids were successful, forging polycyclic products 4a and 4b in 92% and 64% vields, respectively. Heteroarene carboxylic acids. for instance, indole-5-carboxylic acid and N-ethylcarbazole-3carboxylic acid, are also good substrates for this reaction, offering 4c and 4d in 66% and 73% vields, respectively. Of note, for all these cases, the less sterically hindered C-H bond was activated preferably via C-H ruthenation, while ¹H and ¹³C NMR spectra revealed opposite regioselectivity for products 3p, 3s, and 4c, which is in line with the prior observations by Schlosser, Chatani, and others.^[14]

The directing efficacy of the acid functionality under the current conditions is also intriguing. When aromatic acid substrates bearing additional auxiliary (directing group) such as ketone, acetanilide, sulfonamide or pyridyl group were examined, weak *O*-coordination of carboxylic acid turned out responsible to control the site-selectivity, giving phthalides **4e–4i** in 65–72% yields (Scheme 2). The scale-up was also compatible and product **3a** was prepared in gram scale with 91% yield (Scheme 2).

This ruthenium-catalyzed cross-dehydrogenative coupling protocol is not restricted only to vinyl phosphonates. Under the standard conditions, coupling with other olefins such as phenyl vinyl sulfone, acrylic acid esters, and acrylonitrile rendered corresponding phthalides **6a–6h** in good to excellent yields (Scheme 3). The present conditions also accommodate internal alkyne for annulation, producing **6i** in 84% yield (Scheme 3).^[15a] On the other hand, the desired annulative product did not form



Scheme 3. Further scope of the annulation reaction of aromatic acids. [a] Diphenylacetylene (1.5 equiv) was used as a coupling partner.



Scheme 4. Oxidative C–H olefination of aryl carboxylic acids with styrene.

when terminal alkyne such as phenyl acetylene was tested as a coupling partner under the catalytic conditions.^[15b,c] Also, when styrene is employed as a coupling partner, cross-dehydrogenative product **8a** was not detected with the recovery of *ortho*-toluic acid **1a**, suggesting a modified reaction condition is necessary (Scheme 4). When solvent was changed to ethanol, olefinated product **8a** was formed in 60% yield. Further screening revealed KOH as the most effective base for ruthenium catalysis, delivering **8a** in 83% isolated yield in ethanol at 85 °C under air. Under these conditions, electron-rich aromatic acids offered olefinated products **8b–8d** in good yields, however, poor conversion was observed for electron-deficient 4-(trifluoromethyl)benzoic acid (Scheme 4). The protocol was also effective to transform heteroaromatic carboxylic acid into corresponding styrylated products **8f–8g** in moderate yields.



Scheme 5. Scopes of one-pot sequential mono-olefination process.

Transition-metal-catalyzed C-H olefination reactions of benzoic acids with activated olefins often lead to phthalide

molecules owing to facile oxa-Michael addition onto electrondeficient double bond of generated Heck-type intermediate.[16] Therefore, a ring-opening strategy of phthalide products was conceived to access Heck-type products in a sequential one-pot operation (Scheme 5). Considering the high acidity of the proton attached to α -carbon of phosphonate functionality in **3a**, we envisioned to exploit an E1cB-type process. Accordingly, after completion of the reaction of 1a with diethyl vinyl phosphonate 2a under standard conditions, DBU (1.8 diazabicyclo[5.4.0]undec-7-ene) was introduced and reaction mixture was stirred at room temperature for additional 12 h. Analysis of crude reaction mixture showed the formation of desired Heck-type product, which was isolated after esterification in 91% yield. Following this sequence, other Hecktype products 9b-9g were prepared in high yields directly from arene carboxylic acids, highlighting the flexibility of this protocol (Scheme 5). The protocol was also equally effective with acrylates and acrylonitrile coupling partners, where Heck-type products 9h-9l were isolated in the form of free aromatic acid. which is useful for further synthetic manipulations. Compound 9k was crystallized, and the structure was unambiguously confirmed by X-ray analysis.[13]

A series of control experiments has been conducted to penetrate the mechanistic insights (Scheme 6). When the reaction was performed with D_2O under the optimal conditions, an excellent level of deuterium incorporation was observed in the *ortho*-position of acid **1a**, confirming the reversible nature of the C–H ruthenation step (Scheme 6a). In the presence of



Scheme 6. Mechanistic investigations for cross-dehydrogenative annulation reaction with diethyl vinyl phosphonate.

radical scavengers, such as 1,1-diphenylethylene, TEMPO, and BHT, annulative product **3g** was formed in significant amount,

invalidating the involvement of any radical intermediate in the reaction (Scheme 6b). Furthermore, while both the kinetic isotope effect values obtained via intermolecular competitive experiment ($p_{\rm H}/p_{\rm D}$ = 1.55) and independent parallel experiment ($k_{\rm H}/k_{\rm D}$ = 1.71) are significant, the involvement of C–H bond cleavage in the rate-determining step is not affirmative owing to reversible nature of the C–H metalation step (Scheme 6c). Further, intermolecular competition experiments revealed that electronically different aromatic acids produced comparable yields of respective products, favoring concerted-metalation-deprotonation (CMD) mechanism for C–H bond activation process (Scheme 6d).

Based on the above control experiments and literature precedents,^[6] a reaction mechanism has been proposed in Scheme 7. In presence of Ru(II) catalyst and acetate base, arene carboxylic acid 1 forms the metalacycle I. Subsequent coordinative insertion of olefin (2/5/7) generates ruthenacycle III, which experiences a β -hydride elimination to give intermediate IV. Then. reductive elimination produces alkenvlated intermediate V and Ru(0) species. The intermediate v spontaneously undergoes intramolecular oxa-Michael addition, providing the annulated coupling product (3/4/6) and the active Ru(II) catalyst is regenerated from Ru(0) species in the presence of air to continue the catalytic cycle.



Scheme 7. Plausible reaction mechanism for oxidative C–H alkenylation/annulation protocol.

In summary, a greener cross-coupling reaction of arene carboxylic acids with olefins has been developed based on ruthenium(II)-catalyzed weak coordination-assisted site-selective C-H bond activation strategy in water employing air as the sole oxidant. This operationally simple protocol is scalable, accommodates a variety of olefins, and tolerates a diverse set of common functional groups including free alcohol and amine, and offers valuable phthalide molecules in good to excellent yields. Also, a one-pot protocol involving cross-dehydrogenative coupling and subsequent phthalide ring opening has been accomplished to access *Heck*-type products that are apparently unattainable with activated olefins via transition-metal-catalyzed C-H bond activation of arene carboxylic acids. Further development of environmentally benign catalytic routes for otherwise inert C-H bond functionalization is ongoing in our laboratory.

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Keywords: C–H activation • Cross-dehydrogenative coupling • Ruthenium(II) catalysis • Green synthesis • Aromatic carboxylic acids

- a) P. Anastas, J. Warner, Green Chemistry: Theory and Practice, Oxford University Press, New York, **1998**; b) B. Li, P. H. Dixneuf, Chem. Soc. Rev. **2013**, *4*2, 5744; c) T. Kitanosono, K. Masuda, P. Xu, S. Kobayashi, Chem. Rev. **2018**, *118*, 679.
- For selected recent reviews and book chapters on transition-metal-[2] catalyzed C-H activation, see: a) J. Wencel-Delord, T. Dröge, F. Liu, F. Glorius, Chem. Soc. Rev. 2011, 40, 4740; b) P. B. Arockiam, C. Bruneau, P. H. Dixneuf, Chem. Rev. 2012, 112, 5879; c) K. Gao, N. Yoshikai, Acc. Chem. Res. 2014, 47, 1208; d) M. Zhang, Y. Zhang, X. Jie, H. Zhao, G. Li, W. Su, Org. Chem. Front. 2014, 1, 843; e) O. Daugulis, J. Roane, L. D. Tran, Acc. Chem. Res. 2015, 48, 1053; f) S. Dana, M. R. Yadav, A. K. Sahoo, Top. Organomet. Chem. 2015, 55, 189; g) J. He, M. Wasa, K. S. L. Chan, Q. Shao, J.-Q. Yu, Chem. Rev. 2017, 117, 8754; h) P. Nareddy, F. Jordan, M. Szostak, ACS Catal. 2017, 7, 5721; i) Y. Park, Y. Kim, S. Chang, Chem. Rev. 2017, 117, 9247; j) C. S. Wang, P. H. Dixneuf, J. F. Soulé, Chem. Rev. 2018, 118, 7532; k) C. Sambiagio, D. Schönbauer, R. Blieck, T. Dao-Huy, G. Pototschnig, P. Schaaf, T. Wiesinger, M. F. Zia, J. Wencel-Delord, T. Besset, B. U. W. Maes, M. Schnürch, Chem. Soc. Rev. 2018, 47, 6603; I) C. Shan, L. Zhu, L.-B. Qu, R. Bai, Y. Lan, Chem. Soc. Rev. 2018, 47, 7552; m) P. Gandeepan, T. Müller, D. Zell, G. Cera, S. Warratz, L. Ackermann, Chem. Rev. 2019, 119, 2192; n) A. Mandal, S. Dana, D. Chowdhury, M. Baidya, Chem. Asian J. 2019, 14, 4074; o) S. Rei, Y. Ano, N. Chatani, Chem. Rev. 2020, 120, 1788; p) K. Ghosh, R. K. Rit, M. Shankar, K. Mukherjee, A. K. Sahoo, Chem. Rec. 2020, DOI: 10.1002/tcr.202000063.
- [3] a) B. M. Trost, *Science* **1991**, *254*, 1471; b) B. M. Trost, *Angew. Chem. Int. Ed.* **1995**, *34*, 259; c) P. A. Wender, M. P. Croatt, B. Witulski, *Tetrahedron* **2006**, *62*, 7505; d) P. A. Wender, B. L. Miller, *Nature* **2009**, *460*, 197; e) W. R. Gutekunst, P. S. Baran, *Chem. Soc. Rev.* **2011**, *40*, 1976; f) B. R. Rosen, L. R. Simke, P. S. Thuy-Boun, D. D. Dixon, J.-Q. Yu, P. S. Baran, *Angew. Chem. Int. Ed.* **2013**, *52*, 7317; g) G. S. Grandhi, J. Selvakumar, S. Dana, M. Baidya, *J. Org. Chem.* **2018**, *83*, 12327.
- [4] For selected reviews on twofold C-H functionalization via cross-dehydrogenative coupling, see: a) C.-J. Li, Acc. Chem. Res. 2009, 42, 335; b) C. S. Yeung, V. M. Dong, Chem. Rev. 2011, 111, 1215; c) S.-L. You, J.-B. Xia, Top Curr Chem. 2010, 292, 165; d) S. H. Cho, J. Y. Kim, J. Kwak, S. Chang, Chem. Soc. Rev. 2011, 40, 5068; e) S. I. Kozhushkov, L. Ackermann, Chem. Sci. 2013, 4, 886; f) Y. Wu, J. Wang, F. Mao, F. Y. Kwong, Chem. Asian J. 2014, 9, 26; g) C. Bruneau, P. H. Dixneuf, Top. Organomet. Chem. 2015, 55, 137; h) Y. Yang, J. Lan, J. You, Chem. Rev. 2017, 117, 8787; i) W. Ma, P. Gandeepan, J. Lid, L. Ackermann, Org. Chem. Front. 2017, 4, 1435.
- [5] a) L. Ackermann, A. R. Kapdi, H. K. Potukuchi, S. I. Kozhushkov, in Handbook of Green Chemistry, Ed.: P. T. Anastas, Wiley-VCH, Weinheim 2012, pp. 259; b) Also see ref. 1a.
- [6] a) S. Warratz, C. Kornhaaß, A. Cajaraville, B. Niepötter, D. Stalke, L. Ackermann, *Angew. Chem. Int. Ed.* 2015, *54*, 5513; b) Q. Jiang, C. Zhu, H. Zhao, W. Su, *Chem. Asian J.* 2016, *11*, 356; c) A. Bechtoldt, C. Tirler, K. Raghuvanshi, S. Warratz, C. Kornhaaß, L. Ackermann, *Angew. Chem. Int. Ed.* 2016, *55*, 264; d) N. S. Upadhyay, V. H. Thorat, R. Sato,

P. Annamalai, S.-C. Chuang, C.-H. Cheng, *Green Chem.* **2017**, *19*, 3219; e) A. Bechtoldt, M. E. Baumert, L. Vaccaro, L. Ackermann, *Green Chem.* **2018**, *20*, 398.

- [7] R. A. Sheldon, Green Chem. 2005, 7, 267.
- [8] For selected reviews, see: a) C. Fischmeister, H. Doucet, *Green Chem.*2011, 13, 741; b) B. Li, P. H. Dixneuf, *Chem. Soc. Rev.* 2013, 42, 5744;
 c) T. Welton, *Proc. R. Soc. London, Ser. A* 2015, 471, 1; d) Also see ref. 1c.
- [9] For selected reviews, see: a) K. M. Engle, T. Mei, M. Wasa, J.-Q. Yu, Acc. Chem. Res. 2012, 45, 788; b) S. De Sarkar, W. Liu, S. I. Kozhushkov, L. Ackermann, Adv. Synth. Catal. 2014, 356, 1461; c) R. Manikandan, M. Jeganmohan, Org. Biomol. Chem. 2015, 13, 10420; d) M. P. Drapeau, L. J. Gooßen, Chem. Eur. J. 2016, 22, 18654; e) M. Simonetti, I. Larrosa, Nat. Chem. 2016, 8, 1086; f) M. Font, J. M. Quibell, G. J. P. Perry, I. Larrosa, Chem. Commun. 2017, 53, 5584; g) F. Luo, Chin. J. Org. Chem. 2019, 39, 3084; and references cited therein.
- a) L. Ackermann, J. Pospech, Org. Lett. 2011, 13, 4153; b) H. Zhao, T. Zhang, T. Yan, M. Cai, J. Org. Chem. 2015, 80, 8849.
- [11] a) W.-J. Han, F. Pu, C.-J. Li, Z.-W. Liu, J. Fan, X.-Y. Shi, Adv. Synth. Catal. 2018, 360, 1358; b) G. Zhang, F. Jia, L. J. Gooßen, Chem. Eur. J. 2018, 24, 4537.
- [12] a) G. Lin, S. S.-K. Chan, H.-S. Chung, S.-L. Li, Chemistry and Biological Action of Natural Occurring Phthalides in Studies in Natural Products Chemistry, Vol. 32 (Ed: Atta-ur-Rahman), Elsevier, Amsterdam 2005, pp. 611; b) J. J. Beck, S. Chou, J. Nat. Prod. 2007, 70, 891; c) R. Karmakar, P. Pahari, D. Mal, Chem. Rev. 2014, 114, 6213; d) A. Awasthi, M. Singh, G. Rathee, R. Chandra, RSC Adv. 2020, 10, 12626.
- [13] CCDC numbers 2009447 and 2024902 corresponding to compounds 3z and 9k, respectively, contain the supplementary crystallographic data.
- a) J. Gorecka, C. Heiss, R. Scopelliti, M. Schlosser, *Org. Lett.* 2004, *6*, 4591; b) H. Shiota, Y. Ano, Y. Aihara, Y. Fukumoto, N. Chatani, *J. Am. Chem. Soc.* 2011, 133, 14952; c) P.-S. Lee, T. Fujita, N. Yoshikai, *J. Am. Chem. Soc.* 2011, 133, 17283.
- [15] a) P. Saikia, S. Gogoi, *Adv. Synth. Catal.* 2018, *360*, 2063; b) R. K.
 Chinnagolla, M. Jeganmohan, *Chem. Commun.* 2012, *48*, 2030; c) Also see, ref. 6a.
- [16] For selected review and examples on phthalide synthesis via C–H bond activation/functionalization with activated olefins, see: a) A. Renzetti, K. Fukumoto, *Molecules* 2019, 24, 824; b) M. Miura, T. Tsuda, T. Satoh, S. Pivsa-Art, M. Nomura, J. Org. Chem. 1998, 63, 5211; c) A. Renzetti, H.Nakazawa, C.-J. Li, RSC Adv. 2016, 6, 40626; d) Y.-Q. Zhu, T.-F. Han, J.-L. He, M. Li, J.-X. Li, K. Zhu, J. Org. Chem. 2017, 82, 8598; e) W.-J. Han, F. Pu, J. Fan, Z.-W. Liu, X.-Y. Shi, Adv. Synth. Catal. 2017, 359, 3520; f) A. Mandal, S. Dana, D. Chowdhury, M. Baidya, Asian J. Org. Chem. 2018, 7, 1302; g) Y. Qiu, M. Stangier, T. H. Meyer, J. C. A. Oliveira, L. Ackermann, Angew. Chem. Int. Ed. 2018, 57, 14179; h) A. Mandal, G. Mehta, S. Dana, M. Baidya, Org. Lett. 2019, 21, 5879; i) Also see, in ref. 6 and ref. 10.

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Ruthenium catalysis in water: a greener cross-dehydrogenative coupling reaction of arene carboxylic acids with olefins has been developed based on ruthenium(II)-catalyzed weak coordination-assisted site-selective C–H bond activation strategy in water employing air as the sole oxidant.