OL | Organic Letters

Letter

Cite This: Org. Lett. XXXX, XXX, XXX−XXX

pubs.acs.org/OrgLett

Iridium-Catalyzed Benzylamine C−H Alkenylation Enabled by Pentafluorobenzoyl as the Directing Group

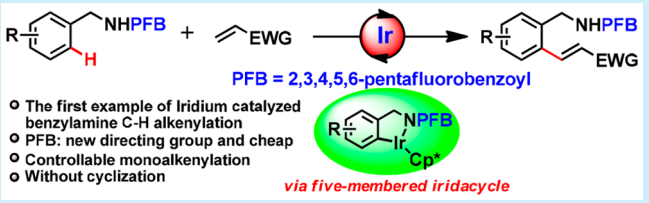
Xiao Yang,[†] Rui Sun,[†] Chunchun Zhang,[‡] Xueli Zheng,*[,†] Maolin Yuan,[†] Haiyan Fu,*[,†] Ruixiang Li,[†] and Hua Chen[†]

[†]Key Laboratory of Green Chemistry & Technology, Ministry of Education College of Chemistry, Sichuan University Chengdu 610064, P.R. China

[‡]Analytical & Testing Center, Sichuan University, Chengdu, Sichuan 610064, P.R. China

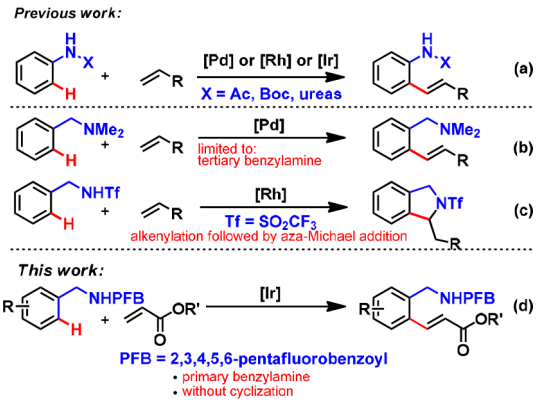
Supporting Information

ABSTRACT: The first iridium-catalyzed oxidative alkeynylation of benzylamines with acrylates enabled by a new directing group pentafluorobenzoyl has been developed. The reaction proceeded efficiently in the presence of silver acetate as oxidant and chlorobenzene as solvent. A good range of benzylamines could be selectively monoalkenylated without interfering with further aza-Michael addition. The kinetic isotope effect experiments showed that C−H activation is not the rate-limiting step. In addition, a five-membered iridacycle species was isolated and established as the possible key intermediate.



Benzylamines have been widely used in the synthetic chemistry community as a class of inexpensive starting matrials,[1] and the installation of the pendant *o*-alkenyl group on it would be serve as a versatile synthetical handle.[2] However, only limited methodology has been available in the literature for the synthesis of such *ortho*-alkenylated benzylic amines.[2a−c,3] In recent years, the transition-metal-catalyzed oxidative alkenylation reaction (Fujiwara−Moritani reaction[4]) would provide a step and an atom-economic way to introduce alkenes group onto arenes via direct C−H activation. Since its discovery, it has been utilized to accomplish the *ortho*-alkenylation of a variety of arene compounds,[5] and the activated olefin−acrylates are widely used as the alkenylating reagents.[5a,c,d,g,6] Generally, a suitable directing group is required to ensure the *ortho* site-selectivty. For example, anilines could successfully undergo *ortho*-selective alkenylation through assistance by different directing groups, such as Ac,[7f] Boc,[7h] and ureas,[7g] under palladium,[7b,c,i] rhodium,[7d−h] or iridium[7a] catalysis (Scheme 1a). Compared with anilines, the oxidative alkenylation of benzylamines substrates is rarely reported. An elegant palladium-catalyzed *ortho* alkenylation of *N,N*-dimethylbenzylamines by carefully tuning the acidity of the reaction condition was reported by Shi in 2007,[8] but the substrates are only limited to the tertiary benzylamine (Scheme 1b). The main challenges met with the oxidative alkenylation between primary benzylamines and acrylates may be as follows: (1) under the oxidative conditions, the benzyl amines are easily to oxidize;[9] (2) the olefin hydroarylation would be a potentially competitive reaction;[10] and (3) since the acrylate is a good Michael addition acceptor, it is difficult to stay in the stage of the alkenylation products, which tend to cyclize via an intramolecular aza-Michael addition.[11] We envisaged that the installation of a proper amide auxiliary would solve the above problems. It not only can increase the stability of the benzylamine but also serve as a directing group to control the chemoselectivity.

Scheme 1. Transitional-Metal-Catalyzed Direct C−H Alkenylation of Anilines and Benzylamines



As mentioned above, a directing group played a vital role in the *ortho*-C−H functionalization; in some cases, it even could completely switch the reaction selectivity.[12] An elegant example has been reported by the Chang group.[13] By employing a different directing group, they can selectively control the C−H alkenylation or the hydroarylation between the reaction of arene and olefins. Only one example of primary benzylamine alkenylation with acrylates was reported by the

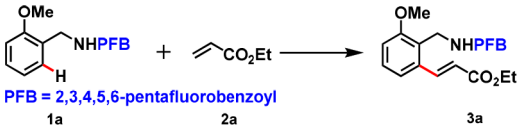
Received: December 15, 2018

DOI: 10.1021/acs.orglett.8b04005
Org. Lett. XXXX, XXX, XXX−XXX

Kim group[14] in 2014, where they utilized a triflamide auxiliary to realize the Rh(III)Cp*-catalyzed benzylamine alkenylation, but the product rapidly cyclized into the isoindolines (Scheme 1c). Inspired by the seminal discovery of an amide auxiliary $CONHAr_F$ (Ar_F = 2,3,5,6-tetrafluoro-4-(trifluoromethyl)-aniline) group by Yu,[15] which is a well-behaved auxiliary in the ortho-functionalization of benzoic acids, we herein demonstrate the successful development of the $NHCOAr_F$ (ArF = 2,3,4,5,6-pentafluorobenzoyl) amide auxiliary to enable the benzylamine alkenylation without further cyclization. By using 2,3,4,5,6-pentafluoro-*N*-(benzyl)benzamide as the substrate and $[IrCp^*Cl_2]_2$ as the catalyst, a highly selective alkenylation of benzylamines can be achieved (Scheme 1d). To the best of our knowledge, this represents the first example of benzylamine oxidative alkenylation with acrylates without interfering with the further aza-Michael addition.

We initiated our studies by coupling 2,3,4,5,6-pentafluoro-*N*-(2-methoxybenzyl)benzamide (**1a**) and ethyl acrylate (**2a**) in the presence of AgOAc as oxidant in toluene (0.1 M) at 100 °C under air for 24 h. Gratifying, 48% yield of the desired alkenylation product **3a** was obtained (Table 1, entry 1). A

Table 1. Optimization of the Reaction Conditions[a]



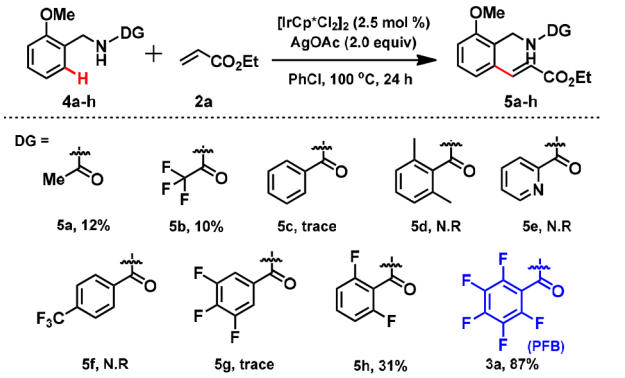
entry	catalyst	oxidant	solvent	yield[b] (%)
1	$[IrCp^*Cl_2]_2$	AgOAc	toluene	48
2	$[IrCp^*Cl_2]_2$	AgOAc	dioxane	26
3	$[IrCp^*Cl_2]_2$	AgOAc	xylene	14
4	$[IrCp^*Cl_2]_2$	AgOAc	DCE	77
5	$[IrCp^*Cl_2]_2$	AgOAc	PhCl	85
6	$[IrCp^*Cl_2]_2$	Ag_2CO_3	PhCl	56
7	$[IrCp^*Cl_2]_2$	$AgNO_3$	PhCl	trace
8	$[IrCp^*Cl_2]_2$	Ag_2O	PhCl	42
9	$[IrCp^*Cl_2]_2$	$Cu(OAc)_2$	PhCl	trace
10[c]	$[IrCp^*Cl_2]_2$	AgOAc	PhCl	76
11[d]	$[IrCp^*Cl_2]_2$	AgOAc	PhCl	92 (87)[e]
12	$Pd(OAc)_2$	AgOAc	PhCl	20
13	$[RhCp^*Cl_2]_2$	AgOAc	PhCl	48

[a]Reaction conditions: **1a** (0.1 mmol), **2a** (0.2 mmol), catalyst (2.5 mmol %), oxidant (2.0 equiv), solvent (1 mL), at 100 °C for 24 h under air in a sealed tube. [b]Yield was determined by ^1H NMR spectroscopy using CH_2Br_2 as an internal standard. [c]**2a** (0.15 mmol). [d]**2a** (0.3 mmol). [e]Isolated yield.

solvent screen illustrated that PhCl provided conversion higher than other commonly used nonpolar solvents (entries 1−5), giving **3a** in 85% yield (entry 5). Then a variety of oxidants were briefly examined in PhCl, and AgOAc proved to be the most efficient oxidant for this reaction (entries 5−9). The ratio of **2a**/**1a** also affected the reaction (entries 5, 10, and 11), and increasing the amount of **2a** to 3 equiv led to a further improvement of the yield to 92%. Other frequently used catalysts in the Fujiwara−Moritani reaction, such as $Pd(OAc)_2$ and $[RhCp^*Cl_2]_2$, are totally ineffective (entries 12 and 13). Therefore, the optimal conditions for this reaction were established as follows: **1a** (0.1 mmol), **2a** (0.3 mmol), $[IrCp^*Cl_2]_2$ (2.5 mol %), and AgOAc (2 equiv) in PhCl (0.1 M) at 100 °C for 24 h. It is worth noting that neither the competitive hydroarylation product between **1a** and **2a** nor the further aza-Michael addition product from **3a** was detected under the reaction conditions.

To clarify the importance of the pentafluorobenzoic acid as the directing group, a series of benzamides (**4a−h**) in which the pentafluorobenzoyl group was replaced by a different directing group, such as acetyl, trifluoroacetyl, benzoyl, 2,6-dimethylbenzoyl, 2-pyridylformyl, 4-(trifluoromethyl)benzoyl, 3,4,5-trifluorobenzoyl, or 2,6-difluorobenzoyl, were subjected to the optimized reaction conditions. Obviously, the investigated directing group only led to either negligible or much lower yield of products. The results congruously showed that the strong electron-withdrawing pentafluorobenzoyl directing group was vital and could significantly improve the reactivity (Scheme 2). Interestingly, the F atom at the *ortho*

Scheme 2. Comparison of Different Directing Groups[a,b]



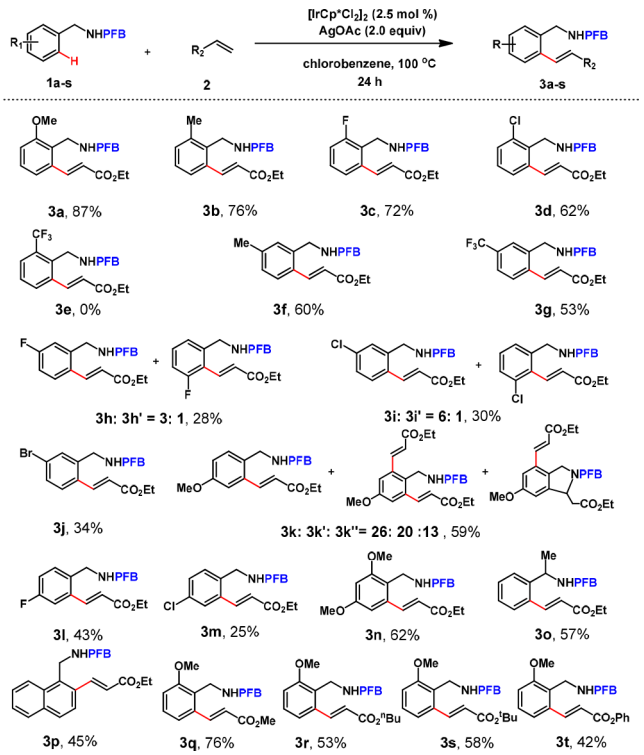
[a]Reaction conditions: **4a−h** (0.1 mmol), **2a** (0.3 mmol), $[IrCp^*Cl_2]_2$ (2.5 mmol %), AgOAc (2.0 equiv) at 100 °C for 24 h under air in a sealed tube. [b]Isolated yield.

position of the benzoyl group is beneficial for the reaction as illustrated by comparison of the results of the last three directing groups.

With the optimized reaction conditions in hand, we set out to explore the scope of this reaction (Scheme 3). The alkenylation of the *ortho*-substituted *N*-benzyl-2,3,4,5,6-pentafluorobenzamides **1a−e** with ethyl acrylate (**2a**) consistently afforded the corresponding monoalkenylated products (**3a−d**) in moderate to high yield of 62−87%, with excellent chemoselectivity, and no Michael addition byproducts were detected. The reaction seems to be more efficient for the electron-rich substrates bearing the electron-donating groups such as methoxy and methyl, whereas the moderately electron-withdrawing groups such as chloro and fluoro groups decreased the yields slightly, and the strong electron-withdrawing *o*-CF_3 completely inhibited the reaction. It is worth noting that in the case of the chloro-substituted substrates neither dehalogenation nor the Mizoroki−Heck byproducts were detected. The remaining chloride atom subsequently could be transformed into other functionalities via the classical cross-couplings. The reaction was compatible with the *meta*-substituted *N*-benzyl-2,3,4,5,6-pentafluorobenzamides **1f−j**, though the yields of the products was relatively lower in comparison to their *ortho*-substituted counterparts (**3f**, **3h**, **3i**, 21−60%). For *m*-Me-, CF_3-, and Br-substituted benzylamines, only monoalkenylation products were obtained, and the alkenylation proceeded exclusively at the less hindered ortho position (**3f**, **3g**, **3j**), while for *m*-F or -Cl-substituted benzylamines, a significant amount of alkenylation occurred

DOI: 10.1021/acs.orglett.8b04005
Org. Lett. XXXX, XXX, XXX−XXX

Scheme 3. Scope of the Reaction[a,b]

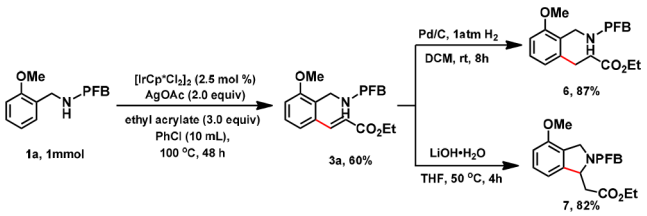


[a]Reaction conditions: **1a−s** (0.1 mmol), **2** (0.3 mmol), $[IrCp^*Cl_2]_2$ (2.5 mmol %), AgOAc (2.0 equiv) at 100 °C for 24 h under air in a sealed tube. [b]Isolated yield.

at the sterically crowded *ortho*-positions (**3h**, **3i**). Surprisingly, the *para*-substituted *N*-benzyl-2,3,4,5,6-pentafluorobenzamides **1k−m** with two equally active sites only afforded the mono-/dialkenylated products in 25−59% total yields (**3k−m**), much lower than the corresponding *ortho*-substituted isomers. These comparative data clearly revealed that the presence of an *ortho* substituent on the aryl ring significantly promoted the reaction. Such an *ortho* effect was also observed in Kim's system.[14] In addition, the disubstituted or *α*-substituted benzyl amines could also undergo the reaction smoothly, giving the product in moderate yields (**3n**, **3o**). In the case of 1-naphthalenemethylamine, the alkenylation occurred completely at the *β*-position with 57% yield (**3p**). Finally, the coupling partner was successfully extended to other esters such as methyl, *n*-butyl, *tert*-butyl, and phenyl acrylates (**3q−t**). It is also worth noting that in most cases studied, the reaction conditions led exclusively to the monoalkenylation products without the undesired further intramolecular cyclization byproducts, except for the 4-MeO-benzylamine in which both the dialkenylation and aza-Michael addition products was detected. However, the electron-deficient *N*,*N*-dimethylacrylamide and acrylonitrile did not react in the present system.

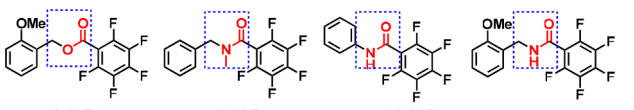
The practicability of present protocol was illustrated by the scale-up preparation of **3a** and the related transformation (Scheme 4). The alkenylation of **1a** on a 1 mmol scale gave **3a** in 60% yield. The double bond in **3a** was smoothly hydrogenated under the catalysis of Pd/C, producing **6** in 87% isolated yield. In addition, **3a** could also be readily converted into the isoindoline in 82% yield by treating with lithium hydroxide monohydrate.

Scheme 4. A 1 mmol Scale Experiment and Transformations



To illustrate the particular suitability of the new directing group PFB for benzylamines. The PFB-based directing group was installed to benzyl alcohol, *N*-methylbenzylamine and aniline, respectively, for comparison with benzylamine substrate (Scheme 5). The fact that no C−H alkenylation

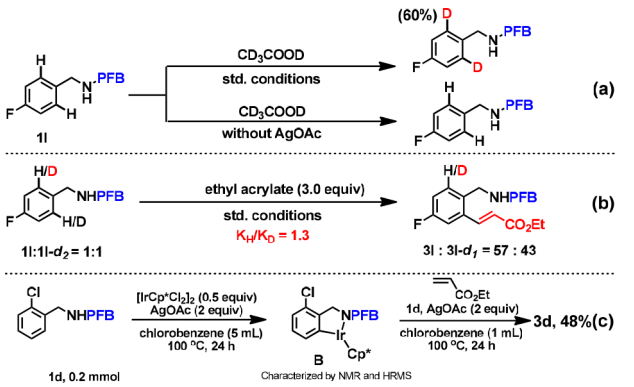
Scheme 5. Controlled Experiment



occurred in the former two substrates **8** and **9** implied the N−H bond is indispensable for the reaction. It was that the amide nitrogen rather than oxygen coordinated to the iridium center. Although there exists an N−H bond in PFB-protected aniline **10**, it still failed to give any alkenylation product. The reason might be that the formation of a strained four-membered iridacycles species is thermodynamically unfavorable. Generally, the carbonyl oxygen in the aniline-based amides is considered to coordinate to metal and serve as the directing group.[7a,f−h] Therefore, the failure to observe any alkenylation product of aniline might also resulted from a shift of lone pair density from the carbonyl oxygen to PFB group, thus disfavoring its coordination to iridium center.

In order to gain a better understanding of the reaction mechanism, several experiments have been conducted. First, an H/D exchange experiment was conducted between 0.2 mmol of **1l** and 10 equiv of acetic acid-d_4 under standard conditions (Scheme 6a). Sixty percent of the *ortho* C−H bond in **1l** was deuterated, showing that a reversible C−H activation process occurred. In contrast, no deuterium incorporation occurred at the *ortho* C−H bond of **1l** in the absence of AgOAc. Therefore, we believe that AgOAc not only plays a role as an oxidant to reoxidize Ir(I) to Ir(III) but also as an efficient promoter for C−H the activation process. Meanwhile, a KIE value of 1.3

Scheme 6. Mechanism Study

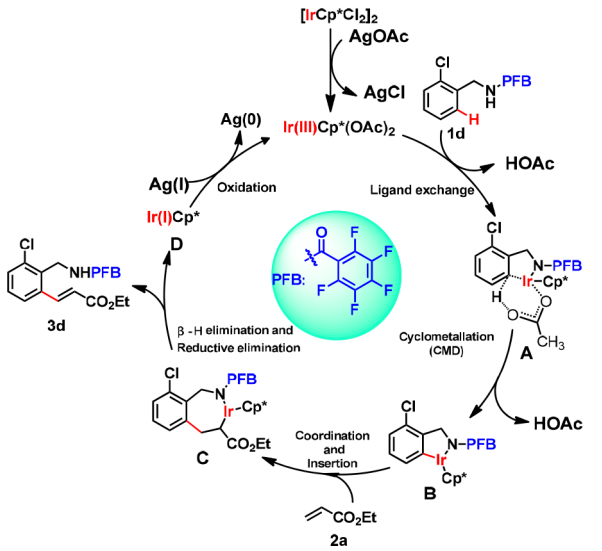


DOI: 10.1021/acs.orglett.8b04005
Org. Lett. XXXX, XXX, XXX−XXX

observed in the alkenylation of **1l**/**1l**-d_2 may support that *ortho* C−H bond cleavage is not involved in the rate-determining step (Scheme 6b). Subsequently, the reaction of **1d** with 0.5 equiv of $[IrCp^*Cl_2]_2$ was performed in the presence of 2.0 equiv of AgOAc in chlorobenzene at 100 °C for 24 h, and the five-membered iridacycle species **B** was successfully separated in the yield of 11%, which was unambiguously characterized by NMR and HRMS. The compound **B** was then used as the catalyst in the reaction between *o*-chlorobenzylamide **1d** and ethyl acrylate under the standard conditions and the product **3d** was obtained in 48% yield (Scheme 6c), thus demonstrating that iridacycle species **B** is possibly the key reaction intermediate.

On the basis of the literature reports[13,14] and our experiment results, we propose a possible mechanism (Scheme 7). First,

Scheme 7. Proposed Reaction Mechanism



AgOAc activated the catalyst by chloride abstraction to give the active $IrCp^*(OAc)_2$ species. It then coordinated to amide nitrogen of **1d** and activated the C−H bond through a concerted metalation−deprotonation (CMD) pathway with the aid of the acetate anion as shown in **A** to afford the intermediate **B**. Subsequently an ethyl acrylate coordinated to **B** followed by double-bond insertion to form the intermediate **C**, which then afforded the alkenylated product **3d** via a sequential *β*-hydride elimination and reductive elimination steps, concomitantly generating the Ir(I) species. Finally, the Ir(I) was further oxidized by AgOAc to regenerate Ir(III) to close the catalytic cycle.

In summary, we have developed the first example of a selective *ortho* C−H bond alkenylation of benzylamines by using $[IrCp^*Cl_2]_2$ as catalyst and PBF as a new directing group. A series of benzylamines bearing different functional groups proceeded well under the present catalytic system, affording alkenylation product in good to excellent yields. In contrast to the previous report on the transitional metal catalyzed oxidative benzylamine alkenylation, the present protocol is characterized by being able to stay in the stage the alkenylation without cyclization by aza-Michael addition. This would allow for further transformation by virtue of the double-bond functionality.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.orglett.8b04005.

Experimental details and full spectroscopic data for all new compounds (PDF)

■ AUTHOR INFORMATION

Corresponding Authors

*E-mail: scufhy@scu.edu.cn.
*E-mail: zhengxueli@scu.edu.cn.

ORCID

Xueli Zheng: 0000-0001-8394-0310
Haiyan Fu: 0000-0002-7185-2062
Ruixiang Li: 0000-0003-0756-3722
Hua Chen: 0000-0003-4248-8019

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We thank the National Natural Science Foundation of China (Nos. 21871187 and 21572137) and the Key Program of Sichuan Science and Technology Project (No. 2018GZ0312) for their financial support. We also thank Chunchun Zhang from the Centre of Testing & Analysis, Sichuan University, for NMR measurements.

■ REFERENCES

(1) (a) Madia, V. N.; Messore, A.; Pescatori, L.; Saccoliti, F.; Tudino, V.; De Leo, A.; Bortolami, M.; Scipione, L.; Costi, R.; Rivara, S.; Scalvini, L.; Mor, M.; Ferrara, F. F.; Pavoni, E.; Roscilli, G.; Cassinelli, G.; Milazzo, F. M.; Battistuzzi, G.; Di Santo, R.; Giannini, G. *J. Med. Chem.* **2018**, *61*, 6918. (b) Abonia, B.; Garay, A.; Castillo, J. C.; Insuasty, B.; Quiroga, J.; Nogueras, M.; Cobo, J.; Butassi, E.; Zacchino, S. *Molecules* **2018**, *23*, 520. (c) Hirashima, H.; Narushima, T.; Kawada, M.; Nakashima, K.; Hanai, K.; Koseki, Y.; Miura, T. *Chem. Pharm. Bull.* **2017**, *65*, 1185. (d) Casimiro, C.; Groppi, J.; Baroncini, M.; La Rosa, M.; Credi, A.; Silvi, S. *Photochem. Photobiol. Sci.* **2018**, *17*, 734.

(2) (a) Mulet, C.; Escolano, M.; Llopis, S.; Sanz, S.; Ramírez de Arellano, C.; Sánchez-Roselló, M.; Fustero, S.; del Pozo, C. *Adv. Synth. Catal.* **2018**, *360*, 2885. (b) Hu, Y.; Xie, Y.; Shen, Z.; Huang, H. *Angew. Chem., Int. Ed.* **2017**, *56*, 2473. (c) Hu, Y.; Shen, Z.; Huang, H. *ACS Catal.* **2016**, *6*, 6785. (d) Toshio, K.; Tsubasa, W.; Kazuhiko, O.; Hiroki, I.; Eisuke, N.; Takeshi, H.; Shunichiro, H.; Hiroshi, S.; Yuji, K.; Ryo, M. PCT Int. Appl. 2014084312, 2014.

(3) (a) Bennasar, M. L.; Roca, T.; Monerris, M.; García-Díaz, D. *J. Org. Chem.* **2006**, *71*, 7028. (b) Suzuki, Y.; Iwase, S.; Hashimoto, K.; Tanaka, S.; Kitamura, M. *Chem. Lett.* **2017**, *46*, 1308. (c) Pierson, J. M.; Ingalls, E. L.; Vo, R. D.; Michael, F. E. *Angew. Chem., Int. Ed.* **2013**, *52*, 13311. (d) Nadres, E. T.; Santos, G. I.; Shabashov, D.; Daugulis, O. *J. Org. Chem.* **2013**, *78*, 9689.

(4) (a) Moritani, I.; Fujiwara, Y. *Tetrahedron Lett.* **1967**, *8*, 1119. (b) Fujiwara, Y.; Moritani, I.; Matsuda, M.; Teranishi, S. *Tetrahedron Lett.* **1968**, *9*, 633. (c) Fujiwara, Y.; Moritani, I.; Danno, S.; Asano, R.; Teranishi, S. *J. Am. Chem. Soc.* **1969**, *91*, 7166.

(5) (a) Engle, K. M.; Wang, D.-H.; Yu, J.-Q. *J. Am. Chem. Soc.* **2010**, *132*, 14137. (b) Mochida, S.; Hirano, K.; Satoh, T.; Miura, M. *Org. Lett.* **2010**, *12*, 5776. (c) Park, S. H.; Kim, J. Y.; Chang, S. *Org. Lett.* **2011**, *13*, 2372. (d) Itoh, M.; Hashimoto, Y.; Hirano, K.; Satoh, T.; Miura, M. *J. Org. Chem.* **2013**, *78*, 8098. (e) Wang, S.-M.; Moku, B.; Leng, J.; Qin, H.-L. *Eur. J. Org. Chem.* **2018**, *2018*, 4407. (f) Deb, A.;

DOI: 10.1021/acs.orglett.8b04005
Org. Lett. XXXX, XXX, XXX−XXX

Hazra, A.; Peng, Q.; Paton, R. S.; Maiti, D. *J. Am. Chem. Soc.* **2017**, *139*, 763. (g) Deb, A.; Bag, S.; Kancherla, R.; Maiti, D. *J. Am. Chem. Soc.* **2014**, *136*, 13602. (h) Dong, Y.; Liu, G. *Chem. Commun.* **2013**, *49*, 8066. (i) Liu, B.; Jiang, H.-Z.; Shi, B.-F. *J. Org. Chem.* **2014**, *79*, 1521.

(6) (a) Li, B.; Ma, J.; Liang, Y.; Wang, N.; Xu, S.; Song, H.; Wang, B. *Eur. J. Org. Chem.* **2013**, *2013*, 1950. (b) Li, J.; Kornhaass, C.; Ackermann, L. *Chem. Commun.* **2012**, *48*, 11343. (c) Ma, W.; Graczyk, K.; Ackermann, L. *Org. Lett.* **2012**, *14*, 6318. (d) Suzuki, Y.; Sun, B.; Yoshino, T.; Kanai, M. *Tetrahedron* **2015**, *71*, 4552. (e) Manikandan, R.; Madasamy, P.; Jeganmohan, M. *ACS Catal.* **2016**, *6*, 230. (f) Fabry, D. C.; Rueping, M. *Acc. Chem. Res.* **2016**, *49*, 1969. (g) Simon, M. O.; Li, C. J. *Chem. Soc. Rev.* **2012**, *41*, 1415. (h) Li, B.; Ma, J.; Wang, N.; Feng, H.; Xu, S.; Wang, B. *Org. Lett.* **2012**, *14*, 736.

(7) (a) Elumalai, K.; Leong, W. K. *Tetrahedron Lett.* **2018**, *59*, 113. (b) Moghaddam, F. M.; Pourkaveh, R.; Karimi, A. *J. Org. Chem.* **2017**, *82*, 10635. (c) Ferlin, F.; Santoro, S.; Ackermann, L.; Vaccaro, L. *Green Chem.* **2017**, *19*, 2510. (d) Patureau, F. W.; Glorius, F. *J. Am. Chem. Soc.* **2010**, *132*, 9982. (e) Takahama, Y.; Shibata, Y.; Tanaka, K. *Chem. - Eur. J.* **2015**, *21*, 9053. (f) Zhang, H. J.; Lin, W.; Su, F.; Wen, T. B. *Org. Lett.* **2016**, *18*, 6356. (g) Morita, T.; Satoh, T.; Miura, M. *Org. Lett.* **2017**, *19*, 1800. (h) Lv, H.; Shi, J.; Huang, J.; Zhang, C.; Yi, W. *Org. Biomol. Chem.* **2017**, *15*, 7088. (i) Boele, M. D. K.; van Strijdonck, G. P. F.; de Vries, A. H. M.; Kamer, P. C. J.; de Vries, J. G.; van Leeuwen, P. W. N. M. *J. Am. Chem. Soc.* **2002**, *124*, 1586.

(8) Cai, G.; Fu, Y.; Li, Y.; Wan, X.; Shi, Z. *J. Am. Chem. Soc.* **2007**, *129*, 7666.

(9) (a) Morimoto, K.; Hirano, K.; Satoh, T.; Miura, M. *Chem. Lett.* **2011**, *40*, 600. (b) Martinez, A. M.; Rodriguez, N.; Gomez-Arrayas, R.; Carretero, J. C. *Chem. - Eur. J.* **2017**, *23*, 11669. (c) Kim, D.-S.; Park, J.-W.; Jun, C.-H. *Adv. Synth. Catal.* **2013**, *355*, 2667.

(10) (a) Ebe, Y.; Onoda, M.; Nishimura, T.; Yorimitsu, H. *Angew. Chem., Int. Ed.* **2017**, *56*, 5607. (b) Grélaud, S.; Cooper, P.; Feron, L. J.; Bower, J. F. *J. Am. Chem. Soc.* **2018**, *140*, 9351. (c) Huang, G.; Liu, P. *ACS Catal.* **2016**, *6*, 809.

(11) Song, G.; Chen, D.; Pan, C. L.; Crabtree, R. H.; Li, X. *J. Org. Chem.* **2010**, *75*, 7487.

(12) (a) De Sarkar, S.; Liu, W.; Kozhushkov, S. I.; Ackermann, L. *Adv. Synth. Catal.* **2014**, *356*, 1461. (b) Leow, D.; Li, G.; Mei, T.-S.; Yu, J.-Q. *Nature* **2012**, *486*, 518. (c) Lee, S.; Lee, H.; Tan, K. L. *J. Am. Chem. Soc.* **2013**, *135*, 18778. (d) Engle, K. M.; Mei, T.-S.; Wasa, M.; Yu, J.-Q. *Acc. Chem. Res.* **2012**, *45*, 788. (e) Lyons, T. W.; Sanford, M. S. *Chem. Rev.* **2010**, *110*, 1147.

(13) Kim, J.; Park, S.-W.; Baik, M.-H.; Chang, S. *J. Am. Chem. Soc.* **2015**, *137*, 13448.

(14) Mishra, N. K.; Park, J.; Sharma, S.; Han, S.; Kim, M.; Shin, Y.; Jang, J.; Kwak, J. H.; Jung, Y. H.; Kim, I. S. *Chem. Commun.* **2014**, *50*, 2350.

(15) (a) Wasa, M.; Engle, K. M.; Yu, J.-Q. *J. Am. Chem. Soc.* **2010**, *132*, 3680. (b) Wu, Q.-F.; Shen, P.-X.; He, J.; Wang, X.-B.; Zhang, F.; Shao, Q.; Zhu, R.-Y.; Mapelli, C.; Qiao, J. X.; Poss, M. A.; Yu, J.-Q. *Science* **2017**, *355*, 499. (c) Pei, Q.-L.; Che, G.-D.; Zhu, R.-Y.; He, J.; Yu, J.-Q. *Org. Lett.* **2017**, *19*, 5860. (d) Wu, Q.-F.; Wang, X.-B.; Shen, P.-X.; Yu, J.-Q. *ACS Catal.* **2018**, *8*, 2577. (e) Zhang, X. G.; Dai, H. X.; Wasa, M.; Yu, J.-Q. *J. Am. Chem. Soc.* **2012**, *134*, 11948.

DOI: 10.1021/acs.orglett.8b04005
Org. Lett. XXXX, XXX, XXX−XXX