Organic LETTERS

Letter

pubs.acs.org/OrgLett

Transition-Metal-Free Direct C−H Arylation of Quinoxalin-2(1*H*)-ones with Diaryliodonium Salts at Room Temperature

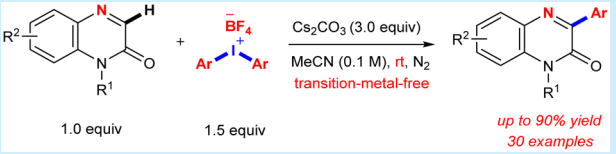
Kun Yin[†] and Ronghua Zhang*[,†,‡]

[†]School of Chemical Science and Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, China

[‡]Shanghai Key Lab of Chemical Assessment and Sustainability, Tongji University, 1239 Siping Road, Shanghai 200092, China

Supporting Information

ABSTRACT: A method of synthesizing 3-arylquinoxalin-2(1*H*)-ones using diaryliodonium tetrafluoroborates under mild conditions is described. This protocol has a wide substrate scope and enables direct C−H functionalization. The synthetic potential of this coupling was explored using a range of readily accessible diaryliodonium salts and quinoxalin-2(1*H*)-ones.



Among all nitrogen-containing heterocycles, the quinoxalin-2(1*H*)-one skeleton, in particular, is widely distributed in an enormous range of compounds (Figure 1).[1] As an important

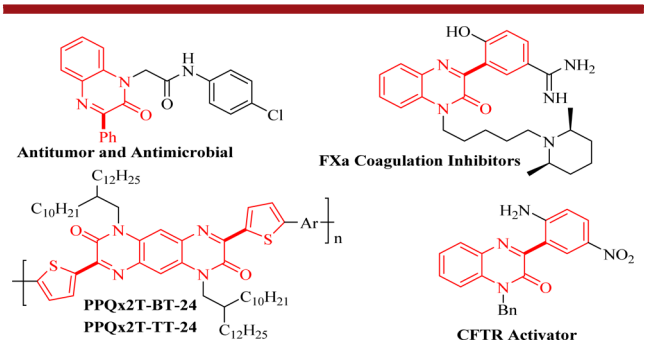
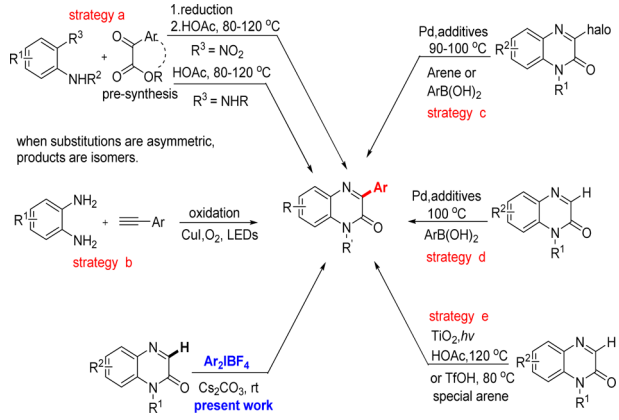


Figure 1. Selected structures bearing a 3-arylquinoxalin-2(1*H*)-one unit.

subclass, most compounds featuring the 3-arylquinoxalin-2(1*H*)-one scaffold have biological activities; examples include aldose reductase inhibitors,[2] FXa coagulation inhibitors,[3] PDGF inhibitors,[4] VEGF inhibitors,[5] prolyl oligopeptidase inhibitors,[6] SCD inhibitors,[7] CDK, 1,2,4,6 inhibitors,[8] STK33 inhibitors,[9] antitumor agents/antimicrobials,[10] and CFTR activators.[11] In addition, 3-arylquinoxalin-2(1*H*)-one polymers can act as semiconductors in the field of materials science.[12] Moreover, the 3-arylquinoxalin-2(1*H*)-one derivatives are very popular substrates employed extensively in transformations to form other subclasses of quinoxaline derivatives as well as in various (organo)catalytic transfomations.[13]

Because of their fascinating profiles, extensive efforts have been devoted to the synthesis of diverse 3-arylquinoxalin-2(1*H*)-ones (Scheme 1);[2,14,15] for instance, the classical thermal condensation from aryl-substituted precursors (Scheme 1, strategy a),[13a,14] the Cu-catalyzed oxidative cyclization of terminal alkynes (Scheme 1, strategy b),[15a] and the Suzuki/Heck coupling of 3-haloquinoxalin-2(1*H*)-ones with arylboronic acid (Scheme 1, strategy c) have been well documented.[2,15b,c] Despite the significance of these compounds, several drawbacks still remain in the aforementioned methods, including the requirement for prefunctionalized substrates, production of isomers, limited substrate scope, expense of the reactants, and use of transition-metal catalysts. Hence, direct strategies for the efficient synthesis of diverse 3-arylquinoxalin-2(1*H*)-ones are still highly desired. In this regard, the direct arylation of C−H bonds in organic compounds has recently emerged as a powerful and ideal method for the formation of carbon−aryl bonds.[16] However, only a handful of examples of direct arylation of quinoxalin-2(1*H*)-ones have been described. In 2013, Messaoudi et al. developed a method for the effective coupling between quinoxalin-2(1*H*)-ones and arylboronic acids using a Pd catalyst under an O_2 atmosphere (Scheme 1, strategy d).[15d] Yuan et al. disclosed a TfOH-catalyzed direct arylation with indoles in air at 80 °C (Scheme 1, strategy e).[15e] Chupakhin et al. also described direct arylation with indoles

Scheme 1. Reported Strategies for Synthesizing 3-Arylquinoxalin-2(1*H*)-ones



Received: January 28, 2017

© XXXX American Chemical Society

DOI: 10.1021/acs.orglett.7b00310
Org. Lett. XXXX, XXX, XXX−XXX

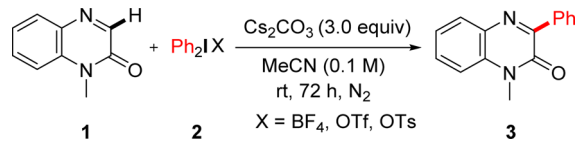
using TiO_2 as photocatalyst in HOAc at 120 °C (Scheme 1, strategy e).[15f] Although these methods represent important advances, they leave room for improvement. For instance, strongly acidic conditions are corrosive; high temperatures are not energy efficient; and Pd agents are expensive and toxic as well as being commonly undesired residual impurities in pharmaceutical products. Therefore, the search for a milder method for synthesizing quinoxalin-2(1*H*)-one derivatives remains an important scientific topic.

In recent years, iodine(III) compounds have been widely studied as mild and environmentally benign agents in modern synthesis because of their advantages, which include good availability, good stability, low toxicity, high reactivity, easy handling,[17a] and good tolerance of diverse functional groups.[17a,18a] Recently, diaryliodonium salts have been employed particularly as arylating agents in various methodologies,[18−20] even in transition-metal-free reactions.[21] Nevertheless, in these approaches for aryl−aryl bonds formation, most substrates coupled with diaryliodonium salts were electron-rich or unbiased arenes.[21a−d] In addition, high temperatures were required during these processes.[21] To the best of our knowledge, direct C−H arylation of quinoxalin-2(1*H*)-ones at room temperature without transition-metal catalyst has not been reported. Herein, we developed extremely mild conditions to access the direct arylation of quinoxalin-2(1*H*)-ones with diaryliodonium salts. This protocol could serve as an effective complement for current methods.

Initially, we used 1-methylquinoxalin-2(1*H*)-one (**1a**) and Ph_2IBF_4 (**2a**) for the model reaction; the results are illustrated in Table 1. The reaction mixture was made up in methyl cyanide (MeCN) (0.1 M) under N_2 at room temperature. The desired product (**3a**) was isolated in 47% yield with **1a** remaining after 48 h (Table 1, entry 1). The structure of **3a** was confirmed unambiguously by NMR spectral analysis and single-crystal X-ray analysis and was in accordance with the literature.[22] To improve the transformation, DMF, with better dissolving capacity, was used instead. Unexpectedly, the yield decreased sharply to 17% (Table 1, entry 2). Bases have been reported to improve reactions employing diaryliodonium salts as reagents.[19a,21b,e,23] To our delight, the yield increased greatly to 70% when $NaHCO_3$ (3.0 equiv) was added, although the reaction time was synchronously prolonged to 72 h (Table 1, entry 3). Inspired by this result, we investigated the solvent effect again. As a result, MeCN was still found to be the best choice (Table 1, entries 4−6). Then, the concentration effect was also tested. Poor phenylation was observed in a reaction conducted using an MeCN concentration of 0.05 M, resulting in 52% yield of **3a** and considerable unreacted **1a** (Table 1, entry 7). In addition, a reaction conducted with an MeCN concentration of 0.2 M did not go to completion during 72 h because of emulsification (Table 1, entry 8).

We next examined the alkali effect (Table 1, entries 9−15). In most cases, the yields increased greatly regardless of K_2HPO_4. In addition, Cs_2CO_3 was found to be the best choice for the reaction, resulting in increased yield (80%) compared to $NaHCO_3$ (Table 1, entry 12). Accordingly, the OTf and OTs anions were investigated, resulting in slightly decreased yields (Table 1, entries 16 and 17). As previously reported, aryl radical formation can be promoted smoothly through visible-light photoredox catalysis at room temperature.[24] Inspired by these previous results, we conducted several parallel experiments. The obtained results (Table 1, entries 20 and 21) show that $Ru(bpy)_3Cl_2·6H_2O$ and blue light alone both slightly improved

Table 1. Optimization of 1-Methylquinoxalin-2(1*H*)-one with Diphenyliodonium Salts[a]



1 2 3

entry	solvent (mL)	base	X	yield[b] (%)
1[c]	MeCN (3.0)		BF_4	47
2[c]	DMF (3.0)		BF_4	17
3	MeCN (3.0)	$NaHCO_3$	BF_4	70
4	DCE (3.0)	$NaHCO_3$	BF_4	49
5	DMSO (3.0)	$NaHCO_3$	BF_4	46
6	dioxane (3.0)	$NaHCO_3$	BF_4	14
7	MeCN (6.0)	$NaHCO_3$	BF_4	52
8	MeCN (1.5)	$NaHCO_3$	BF_4	58
9	MeCN (3.0)	Li_2CO_3	BF_4	73
10	MeCN (3.0)	Na_2CO_3	BF_4	66
11	MeCN (3.0)	K_2CO_3	BF_4	72
12	**MeCN (3.0)**	**Cs_2CO_3**	**BF_4**	**80**
13	MeCN (3.0)	K_2HPO_4	BF_4	45
14	MeCN (3.0)	*t*-BuOK	BF_4	74
15	MeCN (3.0)	DBU	BF_4	58
16	MeCN (3.0)	Cs_2CO_3	OTf	65
17	MeCN (3.0)	Cs_2CO_3	OTs	77
18[d]	MeCN (3.0)	Cs_2CO_3	BF_4	62
19[e]	MeCN (3.0)	Cs_2CO_3	BF_4	78
20[f]	MeCN (3.0)	Cs_2CO_3	BF_4	83
21[g]	MeCN (3.0)	Cs_2CO_3	BF_4	85

[a]Reaction conditions: **1** (0.3 mmol), **2** (1.5 equiv), Cs_2CO_3 (3.0 equiv), dry solvent, N_2, rt, 72 h. [b]Isolated yields. [c]48 h. [d]80 °C, 24 h. [e]Irradiation under blue LEDs (12 W, ∼2 cm distance) with $Ru(bpy)_3Cl_2·6H_2O$ (5 mmol %). [f]$Ru(bpy)_3Cl_2·6H_2O$ (5 mmol %). [g]Irradiation under blue LEDs (12 W, ∼2 cm distance).

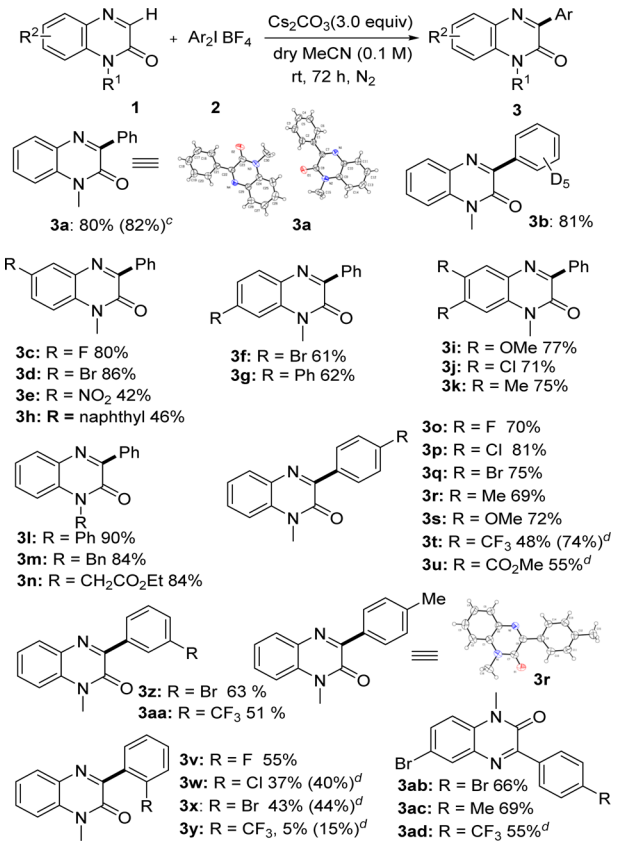
the yield. However, when both were employed, the photoredox process increased the formation of byproducts and decreased the formation of the desired products (Table 1, entry 19). In addition, thermal conditions slightly decreased the yield, although the reaction time was shorter (Table 1, entry 18). Overall, the optimal reaction conditions were set as follows: **1** (0.3 mmol), **2** (1.5 equiv), and Cs_2CO_3 (3.0 equiv) under N_2 in MeCN (0.1 M) at room temperature for 72 h.

With the optimal conditions in hand, we next examined the scope of various quinoxalin-2(1*H*)-ones bearing substituents on the arene rings (Scheme 2, **3a−n**). As shown in Scheme 2, several kinds of carbon−halogen bonds (**3c−d,3,j**) for further functionalization were tolerated under the present conditions.[25] For electron-rich substrates, moderate to good yields were obtained (**3a,b,g,i,k**), with the exception of the naphthyl moiety (**3h**), which might be due to the poor solubility of **1h**. For electron-deficient substrates, the transformation was realized in low yield (**3e**). However, halogen moieties were tolerated well with moderate to good yields (**3c−d,f,j**). Additionally, we screened different protecting groups (**3l−n**). All of the protecting groups tested were tolerated. In addition, a phenyl group was suitable for this reaction with 90% yield (**3l**) regardless of its steric hindrance. These results indicate that the planarity or lack of planarity of the conjugated system did not strongly affect the transformation.

Furthermore, we examined different diaryliodonium salt reagents (Scheme 2, **3o−z** and **3aa−ad**).[26] First, **1b** was

DOI: 10.1021/acs.orglett.7b00310
Org. Lett. XXXX, XXX, XXX−XXX

Scheme 2. Substrate Scope of Arylation of Quinoxalin-2(1*H*)-ones[a,b]

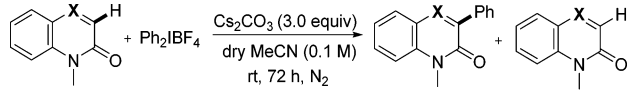


[a]Conditions: **1** (0.3 mmol), **2** (1.5 equiv), Cs_2CO_3 (3.0 equiv), MeCN (3.0 mL), rt, 72 h. [b]Isolated yield. [c]1.0 mmol scale. [d]One week.

employed to examine the effect of deuteration on the arylation. However, it hardly affected the reaction (**3b**). As shown in Scheme 2, both para- and meta-substituted diaryliodonium salts were suitable for this transformation (Scheme 2, **3o−u,z,aa**). In addition, the arylation proceeded well in moderate to good yields. For halide moieties, the yield was as high as 81% (Scheme 2, **3o−q,z**). Notably, for diaryliodonium salts bearing an electron-withdrawing group, a longer reaction time was required (Scheme 2, **3t,u**). A strong steric hindrance effect was obviously observed for ortho-substituted diaryliodonium salts (Scheme 2, **3v−y**). Even if the group was a fluoro atom, the yield still decreased remarkably. Because of the double effects of the *o*-CF_3 moiety, the yield decreased severely, even if the reaction time was prolonged (Scheme 2, **3y**). As shown in Scheme 2, polyfunctional products could also be synthesized in good yields (Scheme 2, **3ab−ad**). Then, cross-coupling reaction of **3ac** with phenylboronic acid was explored (see the Supporting Information for details), giving 90% yield and providing an example for further functionalization.[25]

As reported previously, diaryliodonium salts have been known to transform into aryl radicals via decomposition, and radical mechanisms have been proposed in reactions involving high-valence iodonium salts.[17b,21a,e,23,27] To unambiguously elucidate this transformation, we conducted a preliminary mechanism study. First, TEMPO was introduced into the phenylation process as a radical scavenger (Scheme 3). Only trace desired product was found in the presence of 1.5 or 3.0 equiv of TEMPO, and a considerable amount of **1a** was

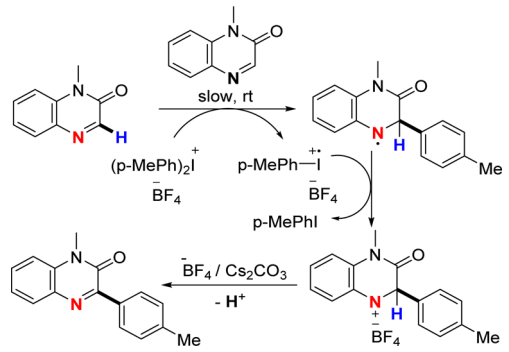
Scheme 3. Controlled Experiments for Preliminary Mechanism Study



	3	Recovery
X = N, No Scavenger	80%	0%
X = N, TEMPO(1.5 equiv)	trace(<3%)	69%
X = N, TEMPO(3.0 equiv)	trace(<3%)	64%
X = CH, No Scavenger	18%	60%

recovered in 69% or 64% yield, respectively. These results indicate that a radical intermediate was involved during this reaction, consistent with the reported aryl radical mechanism (Scheme 4).[21a,b,e] To determine whether rearrangement had

Scheme 4. Proposed Mechanism for Arylation of Quinolin-2(1*H*)-ones



occurred, **3r** was characterized by single-crystal X-ray analysis. The crystal analysis of **3r** clearly revealed that no obvious rearrangement of the aryl radical could be proposed during the reaction. To clarify whether the imine unit was beneficial for the transformation, 1-methylquinolin-2(1*H*)-one was then examined. As a result, 1-methyl-3-phenylquinolin-2(1*H*)-one was isolated in only 18% yield, and 60% of the starting material 1-methylquinolin-2(1*H*)-one was recovered. This result reveals that the imine unit could be helpful for the formation of the phenyl radical via coordination between the nitrogen atom and organic iodide cation.[17b]

In summary, we developed an alternative method for the synthesis of diverse 3-arylquinoxalin-2(1*H*)-ones with diaryliodonium salts via transition-metal-free direct C−H arylation under extremely mild conditions. This reaction has a broad scope of substrates and provides a convenient process with respect to the preparation of 3-arylsubstituted quinoxalin-2(1*H*)-ones. Moreover, various carbon−halogen bonds were well-tolerated, and the halide handles allowed for additional cross-coupling reactions. Mechanistic studies, including radical trapping experiments, revealed that the arylation occurs through an aryl radical mechanism. Our future work will extend this functionalization strategy to other C−H bonds.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.orglett.7b00310.

DOI: 10.1021/acs.orglett.7b00310
Org. Lett. XXXX, XXX, XXX−XXX

Detailed experimental procedures, spectroscopic data of authentic compounds, and characterization of products (PDF)
Crystallographic data for **3a** and **3r** (CIF)

AUTHOR INFORMATION

Corresponding Author

*E-mail: rhzhang@tongji.edu.cn.

ORCID

Ronghua Zhang: 0000-0002-1087-2772

Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

The work was supported by the NSF of China (20972113/B020502). We thank Dr. Wenyan Dan (Tongji University) for analytical support. We thank Dr. Baoyu, Hao (Hutchison Medi Pharma), Mr. Chongfeng, Ge (Hutchison Medi Pharma), Mr. Hao Zou (Astrazeneca), and Prof. Jian Li (Shanghai University) for their suggestions and discussions.

REFERENCES

(1) (a) Li, X.; Yang, K.; Li, W.; Xu, W. *Drugs Future* **2006**, *31*, 979 and references cited therein. (b) Carta, A.; Piras, S.; Loriga, G.; Paglietti, G. *Mini-Rev. Med. Chem.* **2006**, *6*, 1179 and references cited therein.

(2) Qin, X.; Hao, X.; Han, H.; Zhu, S.; Yang, Y.; Wu, B.; Hussain, S.; Parveen, S.; Jing, C.; Ma, B.; Zhu, C. *J. Med. Chem.* **2015**, *58*, 1254.

(3) Willardsen, J. A.; Dudley, D. A.; Cody, W. L.; Chi, L.; McClanahan, T. B.; Mertz, T. E.; Potoczak, R. E.; Narasimhan, L. S.; Holland, D. R.; Rapundalo, S. T.; Edmunds, J. J. *J. Med. Chem.* **2004**, *47*, 4089.

(4) Aoki, K.; Obata, T.; Yamazaki, Y.; Mori, Y.; Hirokawa, H.; Koseki, J.-I.; Hattori, T.; Niitsu, K.; Takeda, S.; Aburada, M.; Miyamoto, K.-I. *Chem. Pharm. Bull.* **2007**, *55*, 255.

(5) Aoki, K.; Koseki, J.-i.; Takeda, S.; Aburada, M.; Miyamoto, K.-i. *Chem. Pharm. Bull.* **2007**, *55*, 922.

(6) Kánai, K.; Arányi, P.; Böcskei, Z.; Ferenczy, G.; Harmat, V.; Simon, K.; Bátori, S.; Náray-Szabó, G.; Hermecz, I. *J. Med. Chem.* **2008**, *51*, 7514.

(7) Koltun, D. O.; Parkhill, E. Q.; Vasilevich, N. I.; Glushkov, A. I.; Zilbershtein, T. M.; Ivanov, A. V.; Cole, A. G.; Henderson, I.; Zautke, N. A.; Brunn, S. A.; Mollova, N.; Leung, K.; Chisholm, J. W.; Zablocki, J. *Bioorg. Med. Chem. Lett.* **2009**, *19*, 2048.

(8) Kawanishi, N.; Sugimoto, T.; Shibata, J.; Nakamura, K.; Masutani, K.; Ikuta, M.; Hirai, H. *Bioorg. Med. Chem. Lett.* **2006**, *16*, 5122.

(9) Weïwer, M.; Spoonamore, J.; Wei, J.; Guichard, B.; Ross, N. T.; Masson, K.; Silkworth, W.; Dandapani, S.; Palmer, M.; Scherer, C. A.; Stern, A. M.; Schreiber, S. L.; Munoz, B. *ACS Med. Chem. Lett.* **2012**, *3*, 1034.

(10) El-Hawash, S. A. M.; Habib, N. S.; Kassem, M. A. *Arch. Pharm.* **2006**, *339*, 564.

(11) Cil, O.; Phuan, P.-W.; Lee, S.; Tan, J.; Haggie, P. M.; Levin, M. H.; Sun, L.; Thiagarajah, J. R.; Ma, T.; Verkman, A. S. *Cell. Mol. Gastroenterol. Hepatol.* **2016**, *2*, 317.

(12) Quinn, J.; Guo, C.; Ko, L.; Sun, B.; He, Y.; Li, Y. *RSC Adv.* **2016**, *6*, 22043.

(13) (a) Xue, Z.-Y.; Jiang, Y.; Peng, X.-Z.; Yuan, W.-C.; Zhang, X.-M. *Adv. Synth. Catal.* **2010**, *352*, 2132. (b) Mao, L.; Sakurai, H.; Hirao, T. *Synthesis* **2004**, *15*, 2535. (c) Mukhina, O. A.; Kuznetsov, D. M.; Cowger, T. M.; Kutateladze, A. G. *Angew. Chem., Int. Ed.* **2015**, *54*, 11516.

(14) (a) Xu, Z.; Dietrich, A. Y. S.; Cappelli, A. P.; Nichol, G.; Hulme, C. *Mol. Diversity* **2012**, *16*, 73. (b) Carta, A.; Briguglio, I.; Piras, S.; Corona, P.; Boatto, G.; Nieddu, M.; Giunchedi, P.; Marongiu, M. E.; Giliberti, G.; Iuliano, F.; Blois, S.; Ibba, C.; Busonera, B.; La Colla, P. L. *Bioorg. Med. Chem.* **2011**, *19*, 7070. (c) Weïwer, M.; Spoonamore, J.; Wei, J.; Guichard, B.; Ross, N. T.; et al. *ACS Med. Chem. Lett.* **2012**, *3*, 1034. (d) Křupková, S.; Funk, P.; Soural, M.; Hlaváč, J. *ACS Comb. Sci.* **2013**, *15*, 20. (e) Dowlatabadi, R.; Khalaj, A.; Rahimian, S.; Montazeri, M.; Amini, M.; Shahverdi, A.; Mahjub, E. *Synth. Commun.* **2011**, *41*, 1650. (f) Shaw, A. Y.; Denning, C. R.; Hulme, C. *Synthesis* **2013**, *45*, 459.

(15) (a) Sagadevan, A.; Ragupathi, A.; Hwang, K. C. *Photochem. Photobiol. Sci.* **2013**, *12*, 2110. (b) Botton, G.; Valeur, E.; Kergoat, M.; Charon, C.; Elbawab, S. Patent WO2009109258A1, 2009. (c) Hussain, S.; Parveen, S.; Hao, X.; Zhang, S.; Wang, W.; et al. *Eur. J. Med. Chem.* **2014**, *80*, 383. (d) Carrër, A.; Brion, J.-D.; Messaoudi, S.; Alami, M. *Org. Lett.* **2013**, *15*, 5606. (e) Han, Y.-Y.; Wu, Z.-J.; Zhang, X.-M.; Yuan, W.-C. *Tetrahedron Lett.* **2010**, *51*, 2023. (f) Utepova, I. A.; Trestsova, M. A.; Chupakhin, O. N.; Charushin, V. N.; Rempel, A. A. *Green Chem.* **2015**, *17*, 4401.

(16) (a) Alberico, D.; Scott, M. E.; Lautens, M. *Chem. Rev.* **2007**, *107*, 174. (b) Bellina, F.; Rossi, R. *Tetrahedron* **2009**, *65*, 10269. (c) Ackermann, L.; Vicente, R.; Kapdi, A. R. *Angew. Chem., Int. Ed.* **2009**, *48*, 9792.

(17) (a) Yoshimura, A.; Zhdankin, V. V. *Chem. Rev.* **2016**, *116*, 3328 and references cited therein. (b) Olofsson, B. *Top. Curr. Chem.* **2015**, *373*, 135.

(18) (a) Aradi, K.; Tóth, B. L.; Tolnai, G. L.; Novák, Z. *Synlett* **2016**, *27*, 1456 and references cited therein. (b) Wagner, A. M.; Hickman, A. J.; Sanford, M. S. *J. Am. Chem. Soc.* **2013**, *135*, 15710. (c) Yang, Y.; Li, R.; Zhao, Y.; Zhao, D.; Shi, Z. *J. Am. Chem. Soc.* **2016**, *138*, 8734.

(19) (a) Modha, S. G.; Greaney, M. F. *J. Am. Chem. Soc.* **2015**, *137*, 1416. (b) Cahard, E.; Male, H. P. J.; Tissot, M.; Gaunt, M. J. *J. Am. Chem. Soc.* **2015**, *137*, 7986. (c) Liu, C.; Wang, Q. *Org. Lett.* **2016**, *18*, 5118. (d) Wu, X.; Yang, Y.; Han, J.; Wang, L. *Org. Lett.* **2015**, *17*, 5654.

(20) (a) Ghosh, R.; Olofsson, B. *Org. Lett.* **2014**, *16*, 1830. (b) Liu, C.; Zhang, W.; Dai, L.-X.; You, S.-L. *Org. Lett.* **2012**, *14*, 4525. (c) Zhou, B.; Hou, W.; Yang, Y.; Feng, H.; Li, Y. *Org. Lett.* **2014**, *16*, 1322. (d) Li, P.; Cheng, G.; Zhang, H.; Xu, X.; Gao, J.; Cui, X. *J. Org. Chem.* **2014**, *79*, 8156.

(21) (a) Yamaoka, N.; Sumida, K.; Itani, I.; Kubo, J.; Ohnishi, Y.; Sekiguchi, S.; Dohi, T.; Kita, Y. *Chem. - Eur. J.* **2013**, *19*, 15004. (b) Wen, J.; Zhang, R.-Y.; Chen, S.-Y.; Zhang, J.; Yu, X.-Q. *J. Org. Chem.* **2012**, *77*, 766. (c) Ackermann, L.; Dell'Acqua, M.; Fenner, S.; Vicente, R.; Sandmann, R. *Org. Lett.* **2011**, *13*, 2358. (d) Castro, S.; Fernández, J. J.; Vicente, R.; Fañanás, F. J.; Rodríguez, F. *Chem. Commun.* **2012**, *48*, 9089. (e) Wang, D.; Ge, B.; Li, L.; Shan, J.; Ding, Y. *J. Org. Chem.* **2014**, *79*, 8607. (f) Gonda, Z.; Novák, Z. *Chem. - Eur. J.* **2015**, *21*, 16801. (g) Huang, T.; Ji, X.; Wu, W.; Liang, F.; Cao, S. *RSC Adv.* **2015**, *5*, 66598. (h) Zhang, Y.; Han, J.; Liu, Z.-J. *Synlett* **2015**, *26*, 2593.

(22) Benzeid, H.; Essassi, E. M.; Saffon, N.; Garrigues, B.; Ng, S. W. *Acta Crystallogr., Sect. E: Struct. Rep. Online* **2009**, *65*, o2323.

(23) (a) Noël-Duchesneau, L.; Lagadic, E.; Morlet-Savary, F.; Lohier, J.-F.; Chataigner, I.; Breugst, M.; Lalevée, J.; Gaumont, A.-C.; Lakhdar, S. *Org. Lett.* **2016**, *18*, 5900.

(24) (a) Li, C.-X.; Tu, D.-S.; Yao, R.; Yan, H.; Lu, C.-S. *Org. Lett.* **2016**, *18*, 4928. (b) Liu, Y.-X.; Xue, D.; Wang, J.-D.; Zhao, C. J.; Zou, Q. Z.; Wang, C.; Xiao, J. L. *Synlett* **2013**, *24*, 507.

(25) de Meijere, A.; Brase, S.; Oestreich, M. *Metal-Catalyzed Cross-Coupling Reactions and More*; Wiley-VCH: Weinheim, 2014.

(26) (a) Bielawski, M.; Olofsson, B. *Org. Synth.* **2009**, *86*, 308. (b) Bielawski, M.; Aili, D.; Olofsson, B. *J. Org. Chem.* **2008**, *73*, 4602. (c) Bielawski, M.; Olofsson, B. *Chem. Commun.* **2007**, 2521. (d) Bielawski, M.; Zhu, M.; Olofsson, B. *Adv. Synth. Catal.* **2007**, *349*, 2610.

(27) (a) Dektar, J. L.; Hacker, N. P. *J. Org. Chem.* **1990**, *55*, 639. (b) Chen, D.; Takai, K.; Ochiai, M. *Tetrahedron Lett.* **1997**, *38*, 8211. (c) Lubinkowski, J. J.; Gimenez Arrieche, C.; McEwen, W. E. *J. Org. Chem.* **1980**, *45*, 2076.

DOI: 10.1021/acs.orglett.7b00310
Org. Lett. XXXX, XXX, XXX−XXX