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Authors

Alexander, Taylor S
Clay, Travis J
Maldonado, Bryan
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Comparative studies of palladium and copper-catalysed γ-arylation of silyloxy furans with diaryliodonium salts

Taylor S. Alexander, Travis J. Clay, Bryan Maldonado, Johny M. Nguyen, David B.C. Martin*

Department of Chemistry, University of California Riverside, Riverside, CA 92521, United States

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ABSTRACT

The γ-arylation of substituted silyl-activated butenolides has been studied using a broad scope of unsymmetrical hypervalent diaryliodonium salts via a palladium- or copper-catalysed coupling reaction, yielding interesting reactivity trends. The mild catalytic conditions and coupling partner variability provide access to synthetically useful building blocks toward the pursuit of aryl-lactone containing natural products and allows for facile diversification.

1. Introduction

Butenolides and other lactones are a common class of structural motifs widely distributed in biologically active natural products (Fig. 1), including the terpene lactones mintlactone, *trans*-crotonin (nor-clerodane) and fraxinellone (limonoid) [1–4]. These moieties are also found in other terpenoids such as salvinorin A (neo-clerodane), which exhibits psychotropic activity [5]. Due to the pervasive occurrence of γ-lactones as a structural component in valuable naturally occurring and pharmaceutically relevant compounds, there is a significant interest in the facile derivatization of butenolides. As a result, many methods for generating substituted butenolides have been reported, including condensations and cross-coupling methods [6–11]. A seminal study performed by Kang and coworkers presented one example of a γ-phenylation using palladium catalysis and Buchwald has reported many examples of arylation with aryl halides under more forcing conditions [12,13]. More recently, MacMillan and Gaunt have developed copper catalysed asymmetric α-arylation reactions between aryl iodonium salts and a variety of silylated nucleophiles, including one cyclic silylketene acetal [14,15]. Despite these advances, a general method for the formation of γ-aryl-lactones under mild conditions has not been reported.

Given our interest in the synthesis of terpene natural products including bioactive lactones, we recognized the potential of a general catalytic arylation to access the furanolactone present in many members (Fig. 1) [1–4,16]. We therefore sought to develop a transition metal-catalysed γ-arylation reaction to access a variety of aryl butenolides by coupling silyloxy furans and diaryliodoniums (Scheme 1, top) [17–20]. One anticipated challenge of this

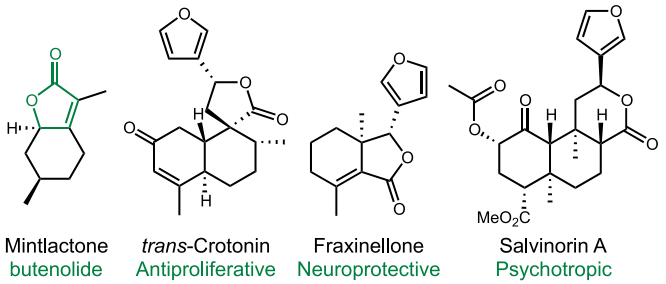

Fig. 1. Biologically active lactone natural products.

* Corresponding author.
E-mail address: dave.martin@ucr.edu (D.B.C. Martin).

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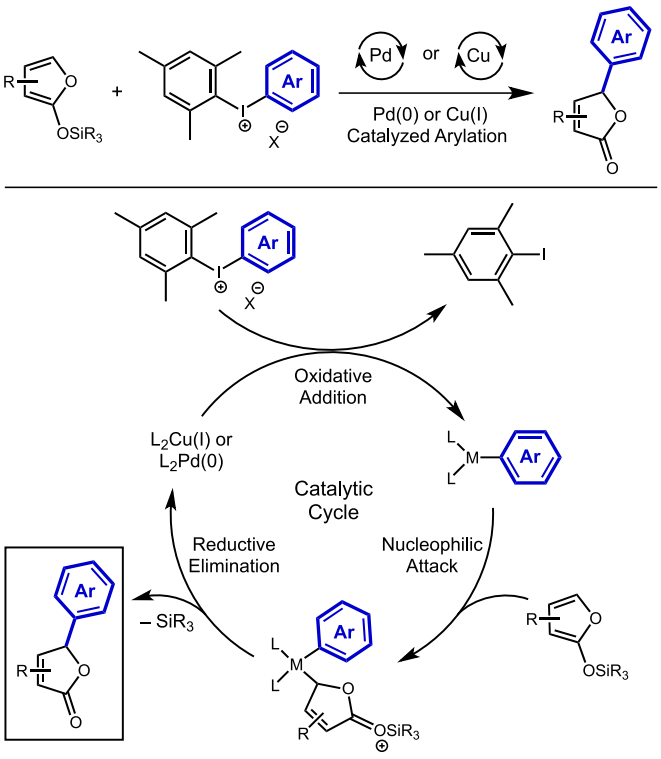
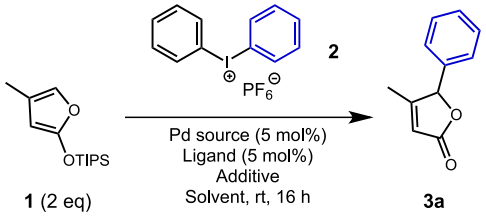


Scheme 1. Proposed transition metal-catalysed γ-arylation reaction and catalytic cycle.

Table 1
Ligand evaluation with symmetric iodonium[a].



1 (2 eq) 3a

Entry	Pd Source	Ligand	Solvent	Additive	Yield
1	$Pd(OAc)_2$	–	DMA/H_2O	–	4%
2	$Pd(OAc)_2$	PCy_3 (10%)	DMA/H_2O	–	39%
3	$Pd_2(dba)_3$	PCy_3 (10%)	DMA/H_2O	–	6%
4	$Pd(OAc)_2$	DavePhos	DMA/H_2O	–	20%
5	$Pd(OAc)_2$	dppp	DMA/H_2O	–	9%
6	$Pd(OAc)_2$	dppe	DMA/H_2O	–	21%
7	$Pd(OAc)_2$	dppbz	DMA/H_2O	–	41%
8	$Pd(OAc)_2$	dppbz	THF	–	31%
9	$Pd(OAc)_2$	dppbz	DCE	–	38%
10	$Pd(OAc)_2$	dppbz	DCM	–	39%
11	$Pd(OAc)_2$	dppbz	DCM	NaOMe	19%
12	$Pd(OAc)_2$	dppbz	DCM	AgOAc	19%
13	$Pd(OAc)_2$	dppbz	DCM	LiOAc	21%
14	$Pd(OAc)_2$	dppbz	DCM	NaOAc(0.5 equiv)	55%
15	$Pd(OAc)_2$	dppbz	DCM	NaOAc(0.8 equiv)	80%

[a] NMR yields determined by dibenzyl ether internal standard. Reaction conditions: Silyloxy furan (2eq), diphenyliodonium (1eq), catalyst (5 mol%) and ligand (5 mol% for bidentate, 10 mol% for monodentate), and additives (0.8eq) in solvent (0.12M).

chemistry is the potential lability of the newly formed methine stereocenter that bears a mildly acidic hydrogen, which could lead to racemization or tautomerization, as observed by Kang [12]. Additionally, we required a method that would only result in monoarylation rather than giving γ,γ-disubstituted products observed by Buchwald. The use of diaryliodonium salts and an activated silyloxy furan nucleophile was anticipated to allow for very mild conditions without the need for a strong base. Furthermore, we were inspired by critical advances in the closely related α-arylation of carbonyl compounds with hypervalent iodonium species that shares many features with the desired reaction [20–26]. With these design parameters in mind, we explored two distinct catalytic systems for the arylation of silyloxy furans to give γ-aryl butenolides as described below.

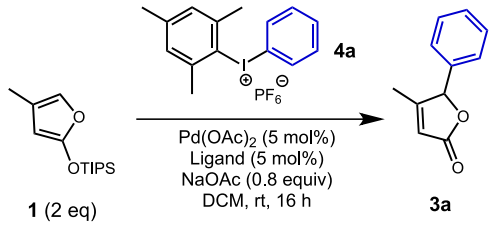
2. Results and discussion

Early optimization efforts were carried out using symmetric diphenyliodonium salt **2** as a model substrate by examining the palladium source, ligands, solvents, additives, iodonium counterion, and temperature (Table 1). Initial conditions were adapted from Kang's singular example, using ligand-free $Pd(OAc)_2$ and an aqueous solvent system of DME/H_2O (4:1), which unfortunately yielded no product [12]. Due to the high lability of TMS-ethers, we explored the use of TBS- and TIPS-ethers. Under modified conditions of DMA/H_2O (4:1) and silyloxy furan **1**, the desired product was generated in 4% yield without isomerization of the alkene to the β, γ -position (Entry 1). A significant increase in reactivity was achieved using PCy_3 as a ligand in DMA/H_2O solvent (39%, Entry 2). We evaluated different palladium sources such as $Pd_2(dba)_3$ (Entry 3, 6%) and $Pd(COD)(CH_2TMS)_2$ (6%, not shown) as reliable precursors of Pd(0); unfortunately, neither source efficiently catalysed the reaction. Additionally, Pd(II) sources such as Buchwald 3rd generation precatalysts were examined with different ligands but offered no advantage [27]. Next, phosphine ligands of various electronic and steric characteristics were evaluated, including mono- and bidentate phosphines. The mono-phosphine ligands surveyed included commonly used Buchwald ligands such as DavePhos (20%, Entry 4), JohnPhos (17%) SPhos (20%), XPhos (15%), however the best monodentate phosphine ligand was found to be PCy_3 (39%, Entry 2). Among bidentate phosphine ligands, dppp (9%, Entry 5) and dppe (21%, Entry 6) did not offer any improvement, but dppbz was found to perform slightly better (41%, Entry 7). Additionally, we evaluated the effect of using NO_3, OTf, and BF_4 as the counterion to diphenyliodonium and found that PF_6 provided the greatest yield (Fig. S1).

During our early optimization studies, we observed that although there was unreacted iodonium the crude reaction mixture after 16 h, the silyloxy furan was consumed, in large part by desilylation under the reaction conditions. Additionally, palladium nanoparticles were routinely observed to precipitate from the reaction mixture. An NMR time study revealed that in the presence of water, full degradation of silyl enol ether **1** occurred within a couple hours. To address this, the solvent system was examined in an effort to exclude water as a co-solvent (Table 1, Entries 8–10). Upon switching to DCM, it was found that the silyloxy furan no longer degraded, the reaction time was dramatically decreased, and the precipitation of palladium was no longer observed. At this point, more than 60 additives were evaluated in an effort to improve the yield (Entries 11–15). It was observed that acetate salts generally out-performed most other types of additives, including other organic and inorganic bases. These extensive optimization efforts led to an 80% yield of butenolide **3a** using 0.8 eq NaOAc and diphenyliodonium hexafluorophosphate as the limiting reagent.

With these optimized conditions in hand for the symmetric diphenyliodonium **2**, we investigated the arylation using an unsymmetrical iodonium to explore the generality of this system with

Table 2
Ligand Evaluation with Unsymmetric Iodonium[a].

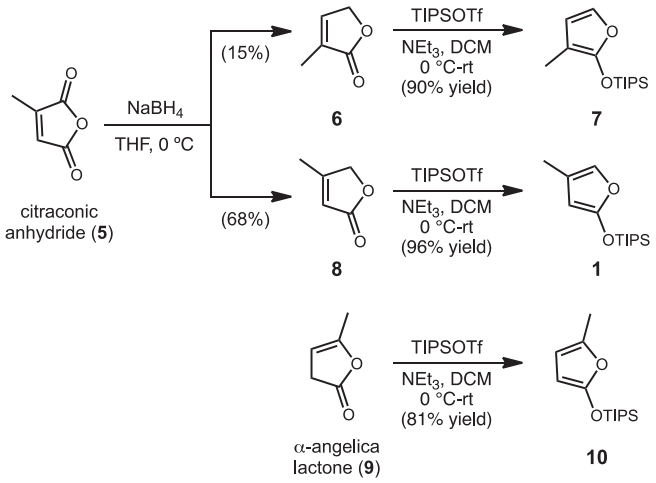


Entry	Ligand	Yield	e.r.
1	P(furyl)$_3$	34%	–
2	P(*o*-tolyl)$_3$	2%	–
3	dppbz	43%	–
4	dppm	2%	–
5	dppe	51%	–
6	dppp	34%	–
7	dppb	8%	–
8	BINAP	61%	–
9	(S)-T-BINAP	50%	44:56 e.r.
10	(R)-SEGPhos	19%	49:51 e.r.
11	(R,R)-Quinox-P	20%	48:52 e.r.
12	(S)-Phox	15%	49:51 e.r.

[a] NMR yields determined by dibenzyl ether internal standard. Reaction conditions: Silyloxy furan (2eq), diphenyliodonium (1eq), catalyst (5 mol%) and ligand (5 mol% for bidentate, 10 mol% for monodentate), and additives (0.8eq) in solvent (0.12 M).

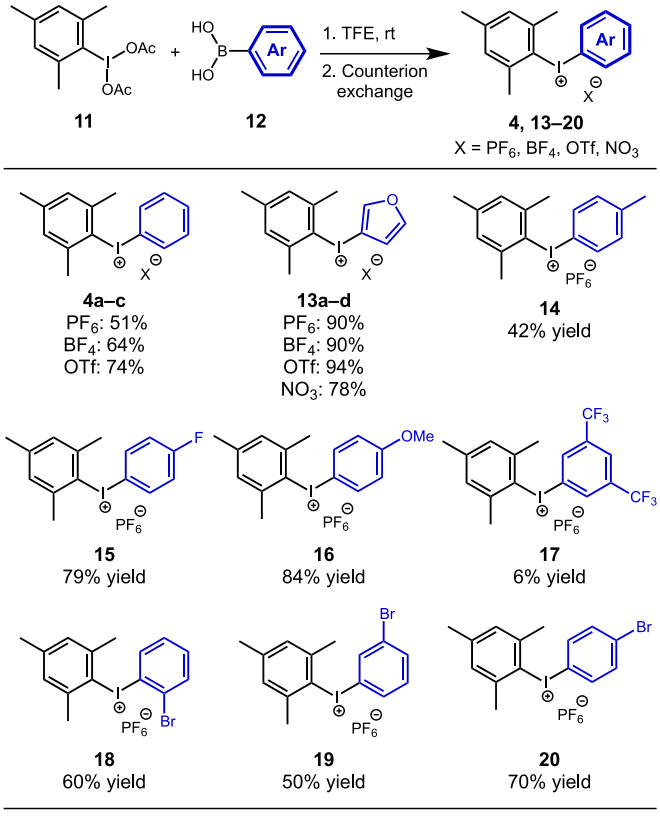
other aryl groups [28]. Using (Ph-I-Mes)PF$_6$ (**9a**), the phenyl group was selectively coupled, generating aryl butenolide **3** in 43% yield (Table 2, Entry 3). Unfortunately, the yield was significantly lower than the optimized model system, therefore reaction conditions were revisited. We evaluated ligands that were structurally and electronically similar to dppbz, such as dppe and dppp, where the bite angle of the phosphines was varied. Further optimization led to a yield of 61% with BINAP (Entry 8). Next, in pursuit of enantioselectivity, a wider array of chiral bidentate phosphine ligands including (S)-T-BINAP, (R,R)-Quinox-P, and (S)-PHOX were evaluated, however, the observed enantioselectivity was very low (up to 12% ee). The use of *rac*-BINAP did, however, provide the highest yield for the unsymmetrical diaryliodonium salt (61%, Entry 8).

With our new optimized conditions in hand, we sought to investigate the scope and tolerance of this novel arylation reaction with various silyloxy furans and unsymmetrical diaryliodonium salts. Accessing the three isomeric methyl-substituted silyloxy furans was performed over 1–2 steps (Scheme 2). Reduction of citraconic anhydride (**5**) with NaBH$_4$ gave a separable mixture of α-Me and β-Me butenolides **6** and **8** [29]. Silylation with TIPS-OTf provided the desired silyloxy furans in excellent yield [30]. The γ-substituted silyloxy furan **10** was accessed directly from commercially available α-angelica lactone (**9**) in 81% yield. The unsymmetrical diaryliodonium salts were most efficiently synthesized by reacting iodomesitylene diacetate with the corresponding aryl boronic acid (Table 3), following the strategy reported by Widdowson [31]. The use of TFE as the solvent obviates the need for a strong Lewis acid, according to the work of Kita and MacMillan, and a variety of aryl boronic acids could be incorporated including acid- and oxidation-sensitive groups such as furan (**13a**–**d**) [32–34]. A wide range of aryl coupling partners with different counter-anions were prepared in moderate to high yields, with the exception of bis-CF$_3$ derivative **17** due to the strong electron-withdrawing effect of the CF$_3$ groups. As shown in Table 4, the arylation of β- and α-methyl silyloxy furans **1** and **7** was very efficient using symmetrical diphenyliodonium **2** and dppbz as ligand, at yields of 80% and 90%,



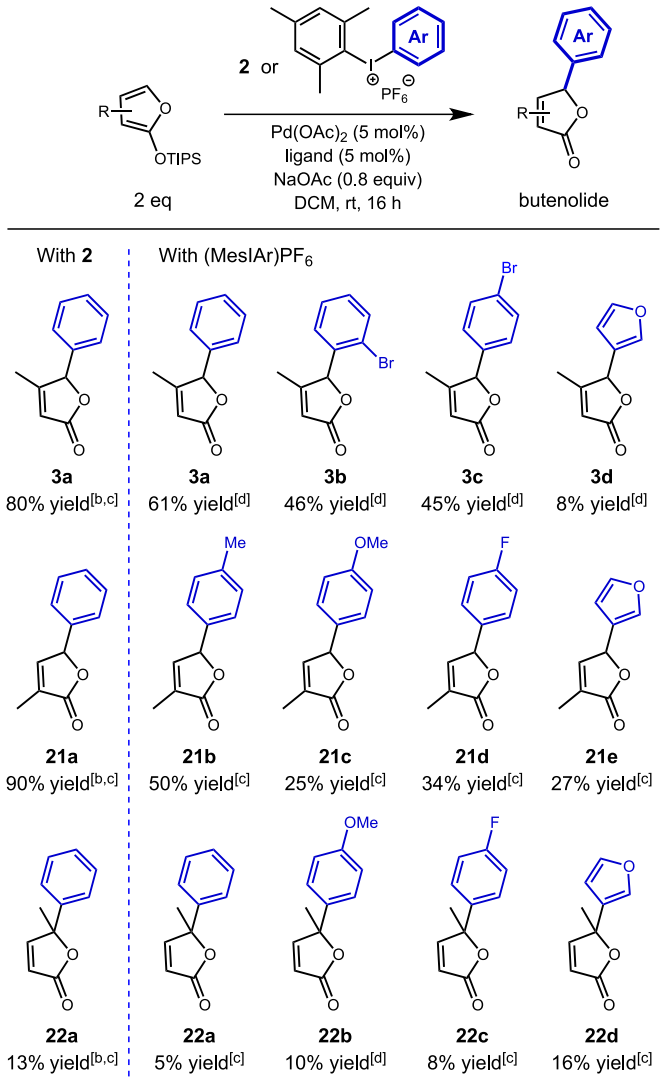
Scheme 2. Silyloxy Furan Substrates.

Table 3
Synthesis of hypervalent iodonium salts.



respectively. In contrast, the arylation of γ-methyl **10** to generate **22a** with a fully substituted carbon proceeded in only 13% yield. Using unsymmetrical diaryliodonium salts, lower yields were obtained. The arylation of the β-methyl silyloxy furan **1** proceeded in 45–61% yield for phenyl and bromophenyl derivatives, including the hindered *o*-bromophenyl **3b**. We observed no loss of the aryl bromide under the mild reaction conditions. The corresponding 3-furyl product **3d** was obtained in only 8% yield due to low conversion and undesired side reactions. The arylation of the α-methyl

Table 4
Scope of Palladium-Catalysed Arylation.

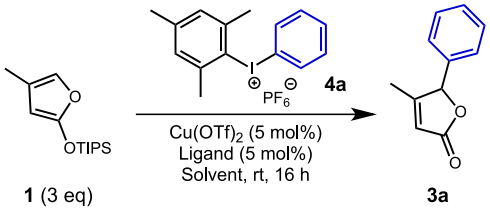


[a] Isolated yields. [b] Diphenyliodonium hexafluoro-phosphate used. [c] Ligands is dppbz. [d]Ligand is BINAP.

silyloxy furan **7** also suffered from reduced yields with electron-rich and electron-deficient aryl groups (**21b**–**e**, 25–50% yield). The 3-furyl group was transferred with modest efficiency in this case (27%). Further optimization for this particular diaryliodonium was pursued, including solvent, ligands and counterions, however the yields of butenolides **3d** and **21e** could not be improved. Furans are sensitive to oxidation and may be incompatible with oxidizing iodonium salts under these reaction conditions. To the best of our knowledge, the only example of a metal catalysed arylation using a 3-furyl iodonium is a C–N bond forming reaction that proceeds in significantly diminished yield compared to other aryl and vinyl coupling partners (42% vs 70–90% yield) [35]. The arylation of the γ-methyl silyloxy furan **10** proved difficult as well, providing only low yields of the corresponding butenolide products (**22a**–**22d**), likely due to steric congestion. Notably, α-arylated products were not observed in any reactions in Table 4. Overall, it was found that greater reactivity was observed with the less sterically hindered α- and β-methyl silyloxy furans using the palladium catalyst system. The poor yields with more challenging substrates, especially the 3-furyl product **3d**, caused us to re-examine our strategy and look for a more efficient catalyst system.

In recent years, several innovative arylation methods have been reported using Cu(I) and Cu(II) precatalysts with various ligand systems [14,15,34–39]. Inspired by the precedent of Gaunt and MacMillan, we were pleased to find that $Cu(OTf)_2$ complexed with bisoxazoline ligands could also catalyse the desired arylation reaction (Table 5) [14,15]. Using the β-methyl silyl-butenolide **1** and $(Ph\text{-}I\text{-}Mes)PF_6$ **4a** as model substrates, the copper catalyst system was optimized with respect to solvent, ligand and other parameters. We re-investigated the counterion effect of the unsymmetric iodonium (Fig. S2) and found that PF_6 (80%) again outperformed BF_4 (53%) and OTf (51%). Additionally, we found that the phenylation proceeded with a greater yield of 80% with the unsymmetrical $(Ph\text{-}I\text{-}Mes)PF_6$ compared to the symmetric diphenyliodonium, which gave a yield of only 63% despite ligand evaluation (Fig. S3). Ultimately, we observed that $Cu(OTf)_2$ and PhBox (5 mol% each) with the unsymmetric $(Ph\text{-}I\text{-}Mes)PF_6$ in DCM at room temperature provided optimal reaction conditions, resulting in an 80% yield, albeit with very low enantioselectivity (Entry 2, Table 5). Other solvents and ligands did not provide any improvement upon these results (Entries 3–8). The scope of the arylation was investigated using this copper catalyst system (Table 6). Interestingly, it was found that when using the copper catalyst system, reactivity generally improved for the β-methyl silyl-butenolide **1**, as observed by good yields of the arylation using the phenyl iodonium (80%, Table 5) as well as the *m*-bromophenyl and *p*-bromophenyl derivatives (85% and 68% for **3f** and **3c**, respectively). This stands in contrast to the palladium catalyst system which showed better reactivity of the α-methyl silyl-butenolide **7**. Again, no loss of aryl bromide was observed with the copper catalyst system. Reactivity of the γ-methyl silyl-butenolide remained quite poor, showing no improvement over the Pd-catalyst system. Overall, copper appears to be generally more effective with the sterically hindered β-Me-silyloxy furan partner, however performs poorly with the α- and γ-Me-silyloxy furan. Unfortunately, the variable efficiency of these transformations did not reveal any notable trends and the low yields of furyl iodonium derivatives (7% yield for **3d**) have hampered further development of this arylation reaction for the synthesis of furanolactone natural products.

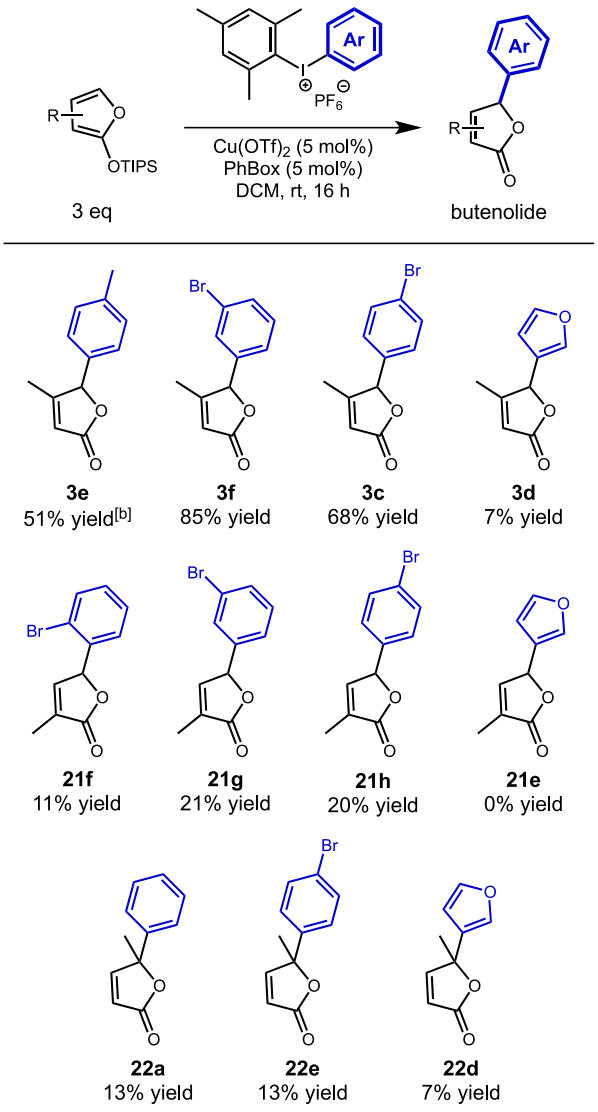
Table 5
Optimization of Copper-Catalysed Arylation.[a]



Entry	Ligand	Solvent	Yield	e.r.
1	None	DCM	0%	–
2	PhBox	DCM	80%	43:57 e.r.
3	*t*-BuBox	DCM	0%	–
4	*i*-PrBox	DCM	73%	42:58 e.r.
5	PhBox	EtOAc	22%	n.d.
6	PhBox	Dioxane	0%	–
7	PhBox	Hexanes	0%	–
8	PhBox	Toluene	25%	43:57 e.r.

[a] Isolated yields, e.r. determined by HPLC.

Table 6
Arylation Scope with Copper-Box Catalyst.[a]



[a] Isolated yields. [b] *i*PrBox used as ligand.

3. Conclusion

In summary, we have developed two transition metal-catalysed arylation method-logies to access aryl butenolides using a palladium or copper catalytic system, both of which provide selective arylation at the γ-position. The main degradation pathway for the silyloxy furan nucleophile, namely proto-desilylation, was overcome by the proper selection of reaction solvent and basic additive. In both cases, these reactions occur under mild conditions at ambient temperature with low catalyst loading. The yields under palladium catalysis are variable with more sterically hindered substrates generally leading to lower yields, in part due to degradation pathways. Interestingly, it was found that better yields were observed for the α-methyl silyl-butenolide when using a palladium catalyst system, while for the β-methyl silyl-butenolide a copper catalyst system resulted in better coupling efficiency. The arylation reaction outlined here allows for a wide range of electronically and sterically varied aromatic groups to be coupled successfully, although the yields remain low for many substrates including the 3-furyl coupling partner. The development of this reaction provides access to a variety of aryl butenolides that are synthetically interesting due to their incorporation as building blocks in natural products and other interesting biologically active molecules. Further efforts toward the development of a highly enantioselective arylation and the implementation of this method in natural product synthesis are ongoing and will be reported in due course.

4. Experimental

4.1. Synthesis of 3-methyl-2(5H)-furanone (**6**)

To a flame-dried vial was added citraconic anhydride (10 mL, 110.22 mmol), THF (250 mL), and $NaBH_4$ (5.24 g, 126.36 mmol). The reaction was stirred at 0 °C for 6 h. The reaction mixture was quenched with H_2O (30 mL), and then acidified with aqueous 6 M HCl. The reaction mixture was then extracted with Et_2O three times, then the combined organic layers were dried over anhydrous Na_2SO_4, filtered, and concentrated *in vacuo*. The resulting crude yellow oil was purified by flash chromatography (SiO_2) using 4:1 Et_2O/hexanes to afford the desired product as a yellow/green oil (1.62 g, 16.53 mmol, 15%). ^1H NMR ($CDCl_3$, 400 MHz) δ 7.14 (m, 1H), 4.77 (t, $J = 2.0$ Hz, 2H), 1.94 (m, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 10.6, 70.2, 129.8, 144.6, 174.8. Spectral data matched literature sources [40].

4.2. Synthesis of 4-methyl-2(5H)-furanone (**8**)

To a flame-dried vial was added citraconic anhydride (10 mL, 110.22 mmol), THF (250 mL), and $NaBH_4$ (5.24 g, 126.36 mmol). The reaction was stirred at 0 °C for 6 h. The reaction mixture was quenched with H_2O (30 mL), and then acidified with aqueous 6 M HCl. The reaction mixture was then extracted with Et_2O three times, then the combined organic layers were dried over anhydrous Na_2SO_4, filtered, and concentrated *in vacuo*. The resulting crude yellow oil was purified by flash chromatography (SiO_2) using 4:1 Et_2O/hexanes to afford the desired product as a yellow/green oil (7.35 g, 550.75 mmol, 68%). ^1H NMR ($CDCl_3$, 400 MHz) δ 5.86 (s, 1H), 4.72 (s, 2H), 2.14 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.21, 166.44, 115.95, 73.83, 13.85. Spectral data matched literature sources [29].

4.3. Synthesis of 2-(triisopropylsiloxy)-3-methyl-furan (**7**)

To a flame-dried round bottom flask was added the alpha-methyl butenolide (1.5 g, 15.29 mmol) and DCM (15 mL). The reaction flask was then cooled to 0 °C. Next, Et_3N (6.3 mL, 45 mmol) and TIPSOTf (4.88 mL, 18 mmol) were added to the reaction flask. The reaction flask was then allowed to warm to room temperature and stirred for 6 h. The reaction was quenched with an aqueous solution of $NaHCO_3$ and extracted with EtOAc. The combined organic layers were washed with brine and then dried over anhydrous Na_2SO_4. The organic layers were then filtered and concentrated *in vacuo*. The crude yellow oil was purified by flash chromatography (SiO_2) using 1% Et_3N in 50:1 Et_2O/EtOAc to afford the desired product as a yellow oil. The crude product was further purified by vacuum distillation to yield the desired product as a colorless oil (3.5 g, 13.75 mmol, 90%). ^1H NMR ($CDCl_3$, 400 MHz) δ 6.74 (d, $J = 2.03$ Hz, 1H), 6.09 (d, $J = 2.03$ Hz, 1H), 1.84 (s, 3H), 1.26 (sep, $J = 7.12$ Hz, 3H), 1.08 (d, $J = 7.12$ Hz, 18H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 153.01, 130.55, 113.74, 91.42, 17.59, 12.38, 8.3. Spectral data matched literature sources [41].

4.4. Synthesis of 2-(triisopropylsiloxy)-4-methyl-furan (**1**)

To a flame-dried round bottom flask was added the beta-methyl butenolide (1.5 g, 15.29 mmol) and DCM (15 mL). The reaction flask was then cooled to 0 °C. Next, Et_3N (6.3 mL, 45 mmol) and TIPSOTf (4.88 mL, 18 mmol) were added to the reaction flask. The reaction flask was then allowed to warm to room temperature and stirred for 6 h. The reaction was quenched with $NaHCO_3$ and extracted with EtOAc. The combined organic layers were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated *in vacuo*. The crude yellow oil was purified by flash chromatography (SiO_2) using 1% Et_3N in 50:1 Et_2O/EtOAc to afford the desired product as a yellow oil. The crude product was further purified by distillation to yield the desired product as a colorless oil (3.73 g, 14.66 mmol, 96%). ^1H NMR ($CDCl_3$, 400 MHz) δ 6.60 (s, 1H), 5.04 (s, 1H), δ 1.96 (s, 3H), 1.26 (sep, $J = 7.12$ Hz, 3H), 1.08 (d, $J = 7.12$ Hz, 18H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 156.79, 128.21, 121.55, 86.31, 17.77, 12.38, 10.6. Spectral data matched literature sources [41].

4.5. Synthesis of 2-(triisopropylsiloxy)-5-methyl-furan (**10**)

To a flame-dried round bottom flask was added angelica lactone (1.5 g, 15.29 mmol) and DCM (15 mL). The reaction flask was then cooled to 0 °C. Next, Et_3N (6.3 mL, 45 mmol) and TIPSOTf (4.88 mL, 18 mmol) were added to the reaction flask. The reaction flask was then allowed to warm to room temperature and stirred for 6 h. The reaction was quenched with $NaHCO_3$ and extracted with EtOAc. The combined organic layers were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated *in vacuo*. The crude yellow oil was purified by flash chromatography (SiO_2) using 1% Et_3N in 50:1 Et_2O/EtOAc to afford the desired product as a yellow oil. The crude product was further purified by distillation to yield the desired product as a colorless oil (3.15 g, 12.38 mmol, 81%). ^1H NMR ($CDCl_3$, 400 MHz) δ 5.74 (s, 1H), 4.96 (d, $J = 2.71$ Hz, 1H), 2.16 (s, 3H) 1.26 (m, 3H), 1.08 (d, $J = 7.12$ Hz, 18H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 155.38, 140.98, 106.14, 83.64, 17.64, 13.58, 12.29. Spectral data matched literature sources [30].

4.6. General Procedure A: synthesis of iodonium salts

To a flame-dried round bottom flask was charged was added the aryl boronic acid (1 eq) and trifluoroethanol (0.22 M). The reaction flask was cooled to 0 °C, then iodomesityl was added (1.05 eq) and then the reaction was allowed to warm to room temperature and stirred for 4 h. The corresponding counterion (NH_4PF_6, NH_4BF_4, AgOTf, or $AgNO_3$) was added as a saturated solution and stirred vigorously for an additional 1 h. After 1 h, the reaction mixture was extracted three times with dichloromethane. The combined organic layers were dried over anhydrous Na_2SO_4, filtered, and concentrated *in vacuo*. If further purification was necessary, trituration in Et_2O was performed. Procedure adapted from Widdowson et al. [31].

4.7. Synthesis of Mesityl(phenyl)iodonium hexafluorophosphate (**4a**)

Prepared according to General Procedure A. Reaction run on 4.10 mmol (500 mg) scale, yielding a white solid (985.3 mg, 2.10 mmol, 51%). ^1H NMR ($CDCl_3$, 400 MHz) δ 7.69 (m, $J = 7.6$ Hz, 2H), 7.57 (m, $J = 7.4$ Hz, 1H), 7.44 (m, $J = 7.6$ Hz, 2H), 7.13 (s, 2H), 2.62 (s, 6H), 2.36 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 145.11, 142.92, 133.12, 132.74, 132.29, 130.74, 118.89, 110.53, 27.18, 21.17. Spectral data matched literature sources [15].

4.8. Synthesis of Mesityl(phenyl)iodonium tetrafluoroborate (**4b**)

Prepared according to General Procedure A. Reaction run on 2.05 mmol (250 mg) scale, yielding a white solid (537.9 mg, 1.3 mmol, 64%). ^1H NMR ($CDCl_3$, 400 MHz) δ 7.69 (m, $J = 7.6$ Hz, 2H), 7.57 (m, $J = 7.4$ Hz, 1H), 7.44 (m, $J = 7.6$ Hz, 2H), 7.13 (s, 2H), 2.62 (s, 6H), 2.36 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 145.11, 142.92, 133.12, 132.74, 132.29, 130.74, 118.89, 110.53, 27.18, 21.17. Spectral data matched literature sources [15].

4.9. Synthesis of Mesityl(phenyl)iodonium triflate (**4c**)

Prepared according to General Procedure A. Reaction run on 2.05 mmol (250 mg) scale, yielding a white solid (716.4 mg, 1.5 mmol, 74%). ^1H NMR ($CDCl_3$, 400 MHz) δ 7.69 (m, $J = 7.6$ Hz, 2H), 7.57 (m, $J = 7.4$ Hz, 1H), 7.44 (m, $J = 7.6$ Hz, 2H), 7.13 (s, 2H), 2.62 (s, 6H), 2.36 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 145.11, 142.92, 133.12, 132.74, 132.29, 130.74, 118.89, 110.53, 27.18, 21.17. Spectral data matched literature sources [15].

4.10. Synthesis of Mesityl(furyl)iodonium hexafluorophosphate (**13a**)

Prepared according to General Procedure A. Reaction run on 2.2 mmol (250 mg) scale, yielding an orange solid (845.2 mg, 1.8 mmol, 90%). ^1H NMR ($CDCl_3$, 400 MHz) δ 7.84 (s, 1H), 7.49 (s, 1H), 7.06 (s, 2H), 6.53 (s, 1H), 2.67 (s, 6H), 2.32 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 148.23, 145.64, 143.93, 141.56, 130.15, 129.22, 127.94, 112.74, 27.07, 21.03 [31].

4.11. Synthesis of Mesityl(furyl)iodonium tetrafluoroborate (**13b**)

Prepared according to General Procedure A. Reaction run on 2.2 mmol (250 mg) scale, yielding an orange solid (845.2 mg, 1.8 mmol, 90%). ^1H NMR ($CDCl_3$, 400 MHz) δ 7.84 (s, 1H), 7.49 (s, 1H), 7.06 (s, 2H), 6.53 (s, 1H), 2.67 (s, 6H), 2.32 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 148.23, 145.64, 143.93, 141.56, 130.15, 129.22, 127.94, 112.74, 27.07, 21.03 [31].

4.12. Synthesis of Mesityl(furyl)iodonium triflate (**13c**)

Prepared according to General Procedure A. Reaction run on 2.2 mmol (250 mg) scale, yielding an orange solid (956.87 mg, 2.1 mmol, 94%). ^1H NMR ($CDCl_3$, 400 MHz) δ 7.84 (s, 1H), 7.49 (s, 1H), 7.06 (s, 2H), 6.53 (s, 1H), 2.67 (s, 6H), 2.32 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 148.23, 145.64, 143.93, 141.56, 130.15, 129.22, 127.94, 112.74, 27.07, 21.03 [31].

4.13. Synthesis of Mesityl(furyl)iodonium nitrate (**13d**)

Prepared according to General Procedure A. Reaction run on 2.2 mmol (250 mg) scale, yielding an orange solid (643.7 mg, 1.7 mmol, 78%). ^1H NMR ($CDCl_3$, 400 MHz), δ 7.84 (s, 1H), 7.49 (s, 1H), 7.06 (s, 2H), 6.53 (s, 1H), 2.67 (s, 6H), 2.32 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz), δ 148.23, 145.64, 143.93, 141.56, 130.15, 129.22, 127.94, 112.74, 27.07, 21.03 [31].

4.14. Synthesis of Mesityl(p-tolyl)iodonium hexafluorophosphate (**14**)

Prepared according to General Procedure A. Reaction run on 1.0 mmol (136 mg) scale, yielding a white solid (202.8 mg, 0.42 mmol, 42%). ^1H NMR ($CDCl_3$, 400 MHz) δ 7.62 (m, $J = 8.5$ Hz, 2H), 7.27 (m, $J = 8.5$ Hz, 2H), 7.13 (s, 2H), 2.64 (s, 6H), 2.39 (s, 3H), 2.36 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz) δ 145.23, 143.85, 142.85, 133.73, 133.56,

130.87, 119.04, 106.47, 27.24, 21.37, 21.18. Spectral data matched literature sources [37].

4.15. Synthesis of Mesityl(4-fluorophenyl)iodonium hexafluorophosphate (**15**)

Prepared according to General Procedure A. Reaction run on 1.0 mmol (140 mg) scale, yielding a tan solid (367 mg, 0.8 mmol, 79%). ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.75 (m, 2H), 7.25 (m, 2H), 7.15 (s, 2H), 2.64 (s, 6H), 2.34 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.77 (d, J_{C-F} = 256.4 Hz), 145.11, 142.66, 136.06, 130.77, 120.31, 120.08, 104.35, 27.18, 21.18. Spectral data matched literature sources [37].

4.16. Synthesis of Mesityl(4-methoxyphenyl)iodonium hexafluorophosphate (**16**)

Prepared according to General Procedure A. Reaction run on 1.0 mmol (152 mg) scale, yielding a tan solid (416.3 mg, 0.8 mmol, 84%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.69 (m, J = 9.2 Hz, 2H), 7.09 (s, 2H) 6.96 (m, J = 9.2 Hz, 2H), 3.80 (s, 3H), 2.63 (s, 6H), 2.32 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.96, 144.86, 142.48, 136.07, 130.68, 127.96, 120.09, 118.52, 55.83, 27.05, 21.05. Spectral data matched literature sources [15].

4.17. Synthesis of Mesityl(3,5-bis(trifluoromethyl)phenyliodonium hexafluorophosphate (**17**)

Prepared according to General Procedure A. Reaction run on 3.94 mmol (1.0 g) scale, yielding a white solid (131.4 mg, 0.2 mmol, 6%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.19 (s, 2H), 7.94 (s, 1H) 7.10 (s, 2H), 2.60 (s, 6H), 2.34 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 144.92, 142.97, 134.47 (q, J_{C-F} = 34.7 Hz), 133.16, 130.42, 125.18, 124.58 (d, J_{C-F} = 273.7 Hz), 120.02, 112.09, 26.97, 21.13. Spectral data matched literature sources [42].

4.18. Synthesis of Mesityl(2-bromophenyl)iodonium hexafluorophosphate (**18**)

Prepared according to General Procedure A. Reaction run on 1.25 mmol (250 mg) scale, yielding a white solid (404 mg, 0.7 mmol, 60%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.77 (m, J = 8.0 Hz, 1H), 7.52 (m, J = 7.3 Hz, 1H), 7.40 (m, J = 7.3 Hz, 1H), 7.24 (s, 2H) 6.93 (m, J = 8.0 Hz, 1H), 2.60 (s, 6H), 2.42 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 146.21, 143.28, 134.76, 133.71, 131.63, 131.30, 124.39, 119.76, 114.87, 27.12, 21.26. Spectral data matched literature sources [43].

4.19. Synthesis of Mesityl(3-bromophenyl)iodonium hexafluorophosphate (**19**)

Prepared according to General Procedure A. Reaction run on 1.25 mmol (250 mg) scale, yielding a white solid (340 mg, 0.6 mmol, 50%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.73 (m, J = 7.8 Hz, 2H), 7.62 (m, J = 8.4 Hz, 1H), 7.30 (m, J = 8.1 Hz, 1H), 7.11 (s, 2H), 2.60 (s, 6H), 2.35 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.01, 142.99, 135.18, 134.78, 133.45, 131.96, 130.66, 125.13, 119.40, 111.00, 27.22, 21.23. Spectral data matched literature sources [15].

4.20. Synthesis of Mesityl(4-bromophenyl)iodonium hexafluorophosphate (**20**)

Prepared according to General Procedure A. Reaction run on 2.05 mmol (250 mg) scale, yielding a white solid (474 mg, 0.9 mmol, 70%). ^{1}H NMR (400 MHz, DMSO-d_6) δ 7.86 (m, J = 8.7 Hz, 2H), 7.71 (m, J = 8.7 Hz, 2H), 7.22 (m, 2H), 2.68 (s, 6H), 2.30 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 143.24, 141.57, 136.26, 134.66, 129.83, 125.76, 122.82, 113.15, 26.28, 20.53. Spectral data matched literature sources [43].

4.21. General Procedure B: synthesis of aryl-butenolides using palladium

To a flame dried vial was added palladium acetate (5 mol%) and 1,2-bis(diphenylphosphino)benzene (5 mol%), followed by the iodonium salt (1 eq) and sodium acetate (0.8 eq). The reaction vial was then pump and backfilled with nitrogen three times. Once under a nitrogen atmosphere, dichloromethane (0.052 M) was added, followed by the silyl enol ether (2 eq). The reaction was stirred for 16 h at room temperature under nitrogen atmosphere. After 16 h, the reaction mixture was extracted three times with diethyl ether. The combined organic layers were dried over anhydrous Na_2SO_4, filtered, and concentrated *in vacuo*. The crude product was purified by flash chromatography (SiO_2) using a 50:50 diethyl ether/hexanes to afford the desired product as a colorless or yellow oil.

4.22. General Procedure C: synthesis of aryl-butenolides using copper

To a flame dried vial in a glovebox was added copper(II) triflate (5 mol%) and (S,S)-2,2′-isopropylidenebis(4-phenyl-2-oxazoline) (5 mol%). The vial was then placed under a nitrogen atmosphere followed by the addition of dichloromethane (0.5 mL). Next, the iodonium (1 eq) was added to a separate vial and then pump and backfilled three times with nitrogen before the addition of dichloromethane (1 mL). The catalyst complex solution was then allowed to stir under nitrogen atmosphere for 10 min before being transferred to the iodonium solution. After the catalyst and iodonium solution were combined, the silyl enol ether (3 eq) was added to the reaction vial. The reaction was allowed to stir at room temperature for 24 h under a nitrogen atmosphere. The reaction mixture was quenched with aqueous sodium bicarbonate and extracted three times with dichloromethane. The combined organic layers were dried over anhydrous Na_2SO_4, filtered, and concentrated *in vacuo*. The crude product was purified by flash chromatography (SiO_2) using a 50:50 diethyl ether/hexanes to afford the desired product as a colorless or yellow oil.

4.23. 4-Methyl-5-phenylfuran-2(5H)-one (**3a**)

Prepared according to General Procedure B using diphenyliodonium-hexafluorophosphate with 5 mol % $Pd(OAc)_2$ and 5 mol % dppbz for 16 h. Reaction was run on 0.165 mmol (70.3 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **3a** as a clear oil. (22.9 mg, 0.13 mmol, 80% yield).

3a: Prepared according to General Procedure B using (Mesityl-I-Phenyl)PF_6 with 5 mol % $Pd(OAc)_2$ and 5 mol % BINAP for 16 h. Reaction was run on 0.165 mmol (77.2 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **3a** as a clear oil. (17.5 mg, 0.10 mmol, 61% yield).

3a: Prepared according to General Procedure C using (Mesityl-I-Phenyl)PF_6 with 5 mol % $Cu(OTf)_2$ and 5 mol % PhBox for 16 h. Reaction was run on 0.165 mmol (77.2 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **3a** as a clear oil. (22.9 mg, 0.13 mmol, 80% yield) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39 (m, 3H), 7.24 (m, 2H), 5.93 (s, 1H), 5.71 (s, 1H), 1.92 (s, 3H) ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.48, 168.60, 134.31, 129.49, 129.10, 126.82, 116.35, 86.60, 14.10.

Spectral data matched literature sources [44].

4.24. 5-(2-Bromophenyl)-4-methylfuran-2(5H)-one (**3b**)

Prepared according to General Procedure B using with 5 mol % $Pd(OAc)_2$ and 5 mol % BINAP for 16 h. Reaction was run on 0.165 mmol (70.3 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **3b** as a clear oil. (19.2 mg, 0.08 mmol, 46% yield) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 (s, J = 8.0 Hz, 1H), 7.35 (s, J = 7.6 Hz, 1H), 7.25 (m, J = 7.6 Hz, 1H), 7.11 (m, J = 8.0 Hz, 1H), 6.36 (s, 1H), 5.95 (s, 1H), 2.00 (s, 3H) ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.34, 168.96, 133.91, 133.34, 130.80, 128.32, 127.56, 123.49, 116.62, 84.62, 14.28. HRMS (ESI) calculated for $C_{11}H_{10}BrO_2$ $[M + H]^+$ 252.9859, found 252.9852.

4.25. 5-(4-Bromophenyl)-4-methylfuran-2(5H)-one (**3c**)

Prepared according to General Procedure B using with 5 mol % $Pd(OAc)_2$ and 5 mol % BINAP for 16 h. Reaction was run on 0.165 mmol (70.3 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **3c** as a clear oil. (18.8 mg, 0.07 mmol, 45% yield).

3c: Prepared according to General Procedure C with 5 mol % $Cu(OTf)_2$ and 5 mol % PhBox for 16 h. Reaction was run on 0.165 mmol (77.2 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **3c** as a clear oil. (28.4 mg, 0.11 mmol, 68% yield) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53 (m, J = 8.4 Hz, 2H), 7.13 (m, J = 8.4 Hz, 2H), 5.94 (s, 1H), 5.67 (s, 1H) 1.92 (s, 3H) ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.04, 168.00, 133.47, 132.37, 128.48, 123.65, 116.65, 85.74, 14.07. HRMS (ESI) calculated for $C_{12}H_{12}O_2$ $[M + H]^+$ 252.9859, found 252.9856.

4.26. 3-Methyl-5-phenyl-2(5H)-furanone (**21a**)

Prepared according to General Procedure B using diphenyliodonium-hexafluorophosphate with 5 mol % $Pd(OAc)_2$ and 5 mol % dppbz for 16 h. Reaction was run on 0.165 mmol (70.3 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **21a** as a clear oil. (25.8 mg, 0.14 mmol, 90% yield).

21a: Prepared according to General Procedure B using (Mesityl-I-Phenyl)PF_6 with 5 mol % $Pd(OAc)_2$ and 5 mol % dppbz for 16 h. Reaction was run on 0.165 mmol (77.2 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **21a** as a clear oil. (2.9 mg, 0.02 mmol, 10% yield) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38 (m, 5H), 7.13 (s, 1H), 5.88 (s, 1H), 2.01 (s, 3H) ^{13}C NMR (100 MHz, $CDCl_3$) δ 148.36, 129.11, 128.96, 126.45, 82.13, 17.95, 11.91, 10.65. Spectral data matched literature sources [45].

4.27. 5-(4-Methylphenyl)-3-methylfuran-2(5H)-one (**21b**)

Prepared according to General Procedure B with 5 mol % $Pd(OAc)_2$ and 5 mol % dppbz for 16 h. Reaction was run on 0.165 mmol (77.2 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford 21b as a clear oil. (15.6 mg, 0.08 mmol, 50% yield) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.16 (m, 4H), 7.11 (m, 1H), 5.85 (m, 1H), 2.36 (s, 3H), 2.00 (s, 3H) ^{13}C NMR (100 MHz, $CDCl_3$) δ 148.43, 139.11, 137.19, 132.10, 130.55, 129.61, 126.50, 82.13, 18.15, 13.41. Spectral data matched literature sources [46].

4.28. 5-(4-Methoxyphenyl)-3-methylfuran-2(5H)-one (**21c**)

Prepared according to General Procedure B with 5 mol % $Pd(OAc)_2$ and 5 mol % dppbz for 16 h. Reaction was run on 0.165 mmol (77.2 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **21c** as a clear oil. (8.4 mg, 0.04 mmol, 25% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.18 (m, J = 8.7 Hz, 2H), 7.10 (s, 1H), 6.92 (m, J = 8.7 Hz, 2H), 5.83 (s, 1H), 3.82 (s, 3H), 2.01 (s, 3H) ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.27, 148.26, 129.69, 128.16, 126.98, 114.32, 82.03, 55.37, 29.71, 10.66. Spectral data matched literature sources [47].

4.29. 5-(4-Fluorophenyl)-3-methylfuran-2(5H)-one (**21d**)

Prepared according to General Procedure B with 5 mol % $Pd(OAc)_2$ and 5 mol % dppbz for 16 h. Reaction was run on 0.165 mmol (77.2 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **21d** as a clear oil. (10.7 mg, 0.06 mmol, 34% yield) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.24 (s, 1H), 7.11 (m, 4H), 5.86 (s, 1H), 2.01 (s, 3H) ^{13}C NMR (100 MHz, $CDCl_3$) δ 148.05, 130.00, 128.50, 116.17, 115.96, 81.51, 29.79, 20.27, 10.74. Spectral data matched literature sources [45].

4.30. 5-Methyl-5-phenylfuran-2(5H)-one (**22a**)

Prepared according to General Procedure B using diphenyliodonium-hexafluorophosphate with 5 mol % $Pd(OAc)_2$ and 5 mol % dppbz for 16 h. Reaction was run on 0.165 mmol (70.3 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **22a** as a clear oil. (3.7 mg, 0.02 mmol, 13% yield).

22a: Prepared according to General Procedure B using (Mesityl-I-Phenyl)PF_6 with 5 mol % $Pd(OAc)_2$ and 5 mol % dppbz for 16 h. Reaction was run on 0.165 mmol (77.2 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **22a** as a clear oil (1.4 mg, 0.01 mmol, 5% yield).

22a: Prepared according to General Procedure C using (Mesityl-I-Phenyl)PF_6 with 5 mol % $Cu(OTf)_2$ and 5 mol % PhBox for 16 h. Reaction was run on 0.165 mmol (77.2 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **22a** as a clear oil. (3.7 mg, 0.02 mmol, 13% yield) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.65 (d, J = 5.6 Hz, 1H), 7.63 (m, 2H), 7.50 (m, 1H), 7.40 (m, 2H), 6.08 (d, J = 5.6 Hz, 1H), 1.84 (s, 3H) ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.41, 160.42, 139.15, 128.87, 128.38, 124.78, 119.37, 88.95, 26.36. Spectral data matched literature sources [48].

4.31. 5-Methyl-5-(4-methoxyphenyl)furan-2(5H)-one (**22b**)

Prepared according to General Procedure B using (Mesityl-I-4-methoxyphenyl)PF_6 with 5 mol % $Pd(OAc)_2$ and 5 mol % dppbz for 16 h. Reaction was run on 0.165 mmol (82.2 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **22b** as a clear oil. (3.3 mg, 0.01 mmol, 10% yield). Spectral data matched literature sources [49].

4.32. 5-Methyl-5-(4-fluorophenyl)furan-2(5H)-one (**22c**)

Prepared according to General Procedure B using (Mesityl-I-4-fluorophenyl)PF_6 with 5 mol % $Pd(OAc)_2$ and 5 mol % dppbz for 16 h. Reaction was run on 0.165 mmol (80.1 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **22c** as a clear oil. (2.5 mg, 0.01 mmol, 8% yield). Spectral data matched literature sources. Spectral data matched literature sources [49].

4.33. 5-(4-Methylphenyl)-4-methylfuran-2(5H)-one (**3e**)

Prepared according to General Procedure C with 5 mol % $Cu(OTf)_2$ and 5 mol % iPrBox for 16 h. Reaction was run on 0.165 mmol (77.2 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **3e** as a clear oil. (15.7 mg, 0.08 mmol, 51% yield) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.20 (m, $J = 8.0$ Hz, 2H), 7.13 (m, $J = 8.4$ Hz, 2H), 5.93 (s, 1H), 5.68 (s, 1H), 3.12 (s, 3H), 1.91 (s, 3H) ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.44, 168.53, 139.46, 131.25, 129.74, 126.79, 116.34, 86.53, 21.25, 14.08. HRMS (ESI) calculated for $C_{12}H_{12}O_2$ $[M + H]^+$ 189.091, found 189.0899.

4.34. 5-(3-Bromophenyl)-4-methylfuran-2(5H)-one (**3f**)

Prepared according to General Procedure B using with 5 mol % $Pd(OAc)_2$ and 5 mol % dppbz for 16 h. Reaction was run on 0.165 mmol (70.3 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **3f** as a clear oil. (14.6 mg, 0.06 mmol, 35% yield).

3f: Prepared according to General Procedure C with 5 mol % $Cu(OTf)_2$ and 5 mol % PhBox for 16 h. Reaction was run on 0.165 mmol (77.2 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **3f** as a clear oil. (35.4 mg, 0.14 mmol, 85% yield) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56 (s, $J = 8.0$ Hz, 2H), 7.43 (s, $J = 7.8$ Hz, 1H), 7.34 (m, $J = 8.0$ Hz, 1H), 7.24 (m, 1H), 6.00 (s, 1H), 5.71 (s, 1H), 1.98 (s, 3H) ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.99, 167.98, 136.66, 132.66, 130.69, 129.78, 125.49, 123.17, 116.67, 85.54, 14.11. HRMS (ESI) calculated for $C_{11}H_{10}BrO_2$ $[M + H]^+$ 252.9859, found 252.9858.

4.35. 5-(3-Bromophenyl)-3-methylfuran-2(5H)-one (**21g**)

Prepared according to General Procedure C with 5 mol % $Cu(OTf)_2$ and 5 mol % PhBox for 16 h. Reaction was run on 0.165 mmol (77.2 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **21g** as a clear oil. (8.7 mg, 0.03 mmol, 21% yield) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49 (m, $J = 7.9$ Hz, 1H), 7.42 (s, 1H), 7.23 (m, $J = 7.9$ Hz, 2H), 7.11 (s, 1H), 5.84 (s, 1H), 2.01 (s, 3H) ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.8, 147.72, 137.46, 132.20, 130.53, 130.01, 129.41, 125.03, 81.10, 29.72, 10.69. Spectral data matched literature sources [51].

4.36. 5-(4-Bromophenyl)-3-methylfuran-2(5H)-one (**21h**)

Prepared according to General Procedure C with 5 mol % $Cu(OTf)_2$ and 5 mol % PhBox for 16 h. Reaction was run on 0.165 mmol (77.2 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **21h** as a clear oil. (8.3 mg, 0.03 mmol, 20% yield) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52 (m, $J = 8.4$ Hz, 2H), 7.16 (m, $J = 8.4$ Hz, 2H), 7.10 (s, 1H), 5.83 (s, 1H), 2.01 (s, 3H) ^{13}C NMR (100 MHz, $CDCl_3$) δ 147.78, 132.16, 128.09, 81.33, 29.72, 10.67. Spectral data matched literature sources [47].

4.37. 5-Methyl-5-(4-bromophenyl)furan-2(5H)-one (**22e**)

Prepared according to General Procedure C using (Mesityl-I-4-Bromophenyl)PF_6 with 5 mol % $Cu(OTf)_2$ and 5 mol % PhBox for 16 h. Reaction was run on 0.165 mmol (90.3 mg) scale. The crude material was purified using silica gel with a solvent system of 50:50 Hexanes/Diethyl Ether to afford **22e** as a clear oil. (5.4 mg, 0.02 mmol, 13% yield). Spectral data matched literature sources [50].

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tet.2019.02.042.

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