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Rh(III)-catalyzed sequential *ortho*- C–H oxidative arylation/cyclization of sulfoxonium ylides with quinones toward 2-hydroxy-dibenzo[*b,d*]pyran-6-ones

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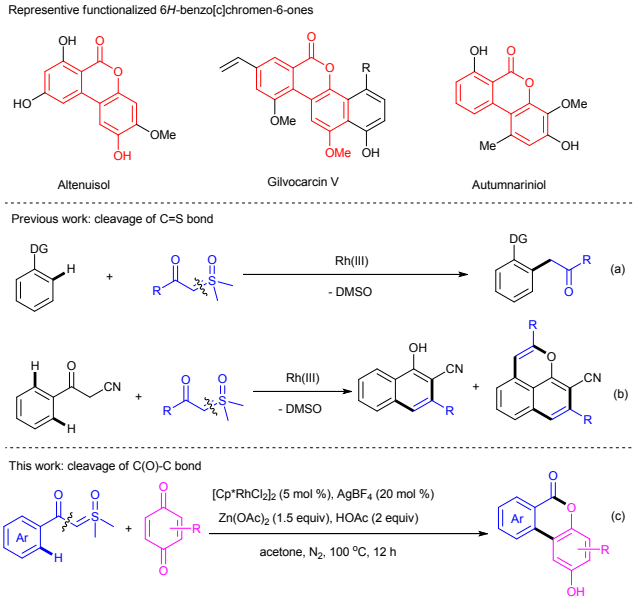
A rhodium(III)-catalyzed *ortho*- C–H functionalization of sulfoxonium ylides followed by intramolecular annulation reactions with quinones was described, where the carbonyl in sulfoxonium ylides served as a chelation group. This protocol leads to the efficient formation of 2-hydroxy-6*H*-benzo[*c*]chromen-6-one derivatives, proceeding with the cleavage of C(O)–S bond in sulfoxonium ylides. This protocol featured with high chemo-selectivity and functional group tolerance, where sulfoxonium ylides acted as the aroyl sources.

6*H*-Benzo[*c*]chromen-6-one derivatives are important substructure motifs, which widely exist in biologically active natural products and medicines,[1] such as altenuisol,[2] Givocarcin V[3] and autumnariniol (Scheme 1, top).[4] Therefore, much effort has been devoted in the construction of these useful frameworks.[5, 6, 7, 8] Among the well-developed procedures, transition-metal-catalyzed intra- or intermolecular direct C–H arylation represents a green and efficient route owning to its high atom economy.[9] For instance, Xu and co-workers developed the Rh(III)-catalyzed oxidative arylation of C–H bond in *N*-methoxybenzamide with hydroquinones toward diverse benzo[*c*]chromen-6-ones derivatives.[10a] Ison demonstrated $[Cp^*IrCl_2]_2$-catalyzed intermolecular C–H functionalization of benzoic acid with benzoquinones in high efficiency.[11] Alternatively, electrochemical intramolecular dehydrogenative lactonization of benzoic acid provided efficient method toward diverse 6*H*-benzo[*c*]chromen-6-ones.[12] Despite the progress made in this field, the construction of these core frameworks proceeding with either new substrates or new strategies on known substrates is still in high desirable.

On the other hand, sulfur ylides served as precursors of metal-carbene for the construction of diverse products.[13] Typically, the utilization of sulfur ylides as C1[14], C3 building block[15] and arene subunit[16] have been well documented. As far as the cleavage of sulfoxonium ylides in organic synthesis is concerned, Li,[14b] Wang,[17] and Aissa[14c] independently reported chelation-assisted functionalization of arene C–H bonds whereas sulfoxonium ylides acted as acylmethyl source proceeding with the cleavage of C=S double bond (Scheme 1a). Meanwhile, Li demonstrated a Rh(III)-catalyzed cascade C–H activation of benzoylacetonitriles and annulation with sulfoxonium ylides toward diverse (dihydro)naphtho[1,8-*bc*]pyrans (Scheme 1b).[16a]



Scheme 1. Representative 6*H*-benzo[*c*]chromen-6-ones and bond cleavage of sulfoxonium ylides

From the synthetic point of view, the further expansion of the applications of sulfoxonium ylides would make progress in organic synthesis. We have noticed the homo-coupling of two sulfoxonium ylides leading to isocoumarins, where one of the sulfoxonium ylides served as the aroyl source proceeding with the cleavage of C(O)–C bond.[17] Moreover, recently, Fan confirmed sulfoxonium ylides took

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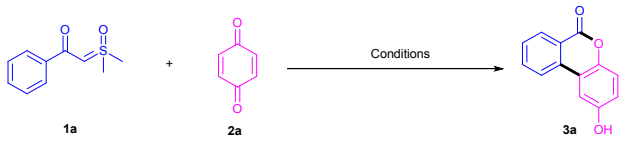
part in the chelation-assisted *ortho*- C-H functionalization in access of functionalized naphthalenones, where the carbonyl in sulfoxonium ylide served as chelation group.[18] Enlightened by these results, we envisioned to develop a novel and facile rhodium(III)-catalyzed sequential C−H functionalization/intramolecular annulation reactions between hydroquinones and sulfoxonium ylides toward 2-hydroxy-6*H*-benzo[*c*]chromen-6-one derivatives (Scheme 1c). In this procedure, the reaction proceeded with the cleavage of C(O)−C bond and sulfoxonium ylides acted as the aroyl sources. Herein, we wish to report it.

Table 1. Selected results for screening the optimized reaction conditions[a]



entry	catalyst	Ag salt	additive	yield[b] (%)
1	$[Cp^*RhCl_2]_2$	$AgSbF_6$	AcOH	58
2	$[Cp^*RhCl_2]_2$	AgNTf	AcOH	50
3	$[Cp^*RhCl_2]_2$	AgOAc	AcOH	trace
4	$[Cp^*RhCl_2]_2$	$AgBF_4$	AcOH	71
5	$[Cp^*RhCl_2]_2$	$AgBF_4$	PivOH	61
6	$[Cp^*RhCl_2]_2$	$AgBF_4$	$Cu(OAc)_2$	66
7	$[Cp^*RhCl_2]_2$	$AgBF_4$	1-AdCOOH	40
8	$[Cp^*RhCl_2]_2$	$AgBF_4$	$Zn(OAc)_2$	75
9[c]	$[Cp^*RhCl_2]_2$	$AgBF_4$	$Zn(OAc)_2$/AcOH	86
10[d]	$[Cp^*RhCl_2]_2$	$AgBF_4$	$Zn(OAc)_2$/AcOH	88
11[d]	$[Ru(p\text{-cymene})Cl_2]_2$	$AgBF_4$	$Zn(OAc)_2$/AcOH	0
12[d]	$[Cp^*Co(CO)I_2]_2$	$AgBF_4$	$Zn(OAc)_2$/AcOH	0
13[d]	$[Cp^*RhCl_2]_2$	$AgBF_4$	$Zn(OAc)_2$/AcOH	84[f], 81[g]
14[d, e]	$[Cp^*RhCl_2]_2$	$AgBF_4$	$Zn(OAc)_2$/AcOH	60
15[d]	--	$AgBF_4$	$Zn(OAc)_2$/AcOH	0

[a] Reaction conditions: sulfoxonium ylide **1a** (0.15 mmol), benzoquinone **2a** (0.3 mmol), catalyst (5 mol %), silver salt (20 mol %), additive (0.3 mmol), acetone (2 mL), 12 h, in a sealed Schlenk tube under N_2 at 100 °C, unless otherwise noted. [b] Isolated yield. [c] $Zn(OAc)_2$ (0.3 mmol), AcOH (0.3 mmol). [d] $Zn(OAc)_2$ (0.225 mmol), AcOH (0.3 mmol). [e] Under O_2. [f] 80 °C. [g] 120 °C. 1-AdCO_2H = 1-Adamantanecarboxylic acid.

Initially, sulfoxonium ylide **1a** (0.15 mmol) and benzoquinone **2a** (0.3 mmol) were selected as the model substrates to optimize the reaction conditions. Firstly, in the presence of $[Cp^*RhCl_2]_2$ (5 mol %), $AgSbF_6$ (20 mol %) and HOAc (0.3 mmol) as the additive, the sequential *ortho*-C−H activation/annulation product 2-hydroxy-6*H*-benzo[*c*]chromen-6-one **3a** was isolated in 58% yield (Table 1, entry 1). Encouraged by this preliminary result, some sliver salts were screened, and $AgBF_4$ (71%) was superior to AgNTf (50%); while AgOAc almost inhibited the reaction (entries 1-4). The additives also have a profound effect in the reaction efficiency, and $Zn(OAc)_2$ (75%) gave better result than those of PivOH (61%), $Cu(OAc)_2$ (66%), and 1-AdCOOH (40%) (entries 4-8). In the presence of $Zn(OAc)_2$ (0.3 mmol) and AcOH (0.3 mmol), the yield dramatically increased to 86% (entry 9). Further studies revealed that 0.225 mmol of $Zn(OAc)_2$ and 0.3 mmol of AcOH was sufficient enough for the best reaction efficiency (entry 10). Other catalysts such as $[Ru(p\text{-cymene})Cl_2]_2$ and $[Cp^*Co(CO)I_2]_2$ all resulted in no reaction (entries 11-12). Additionally, elevating or lowering the reaction temperature all gave inferior results (entry 13). The yield decreased to 60% under O_2 atmosphere. The blank experiment revealed that no reaction took place in the absence of catalyst $[Cp^*RhCl_2]_2$ (entry 15).

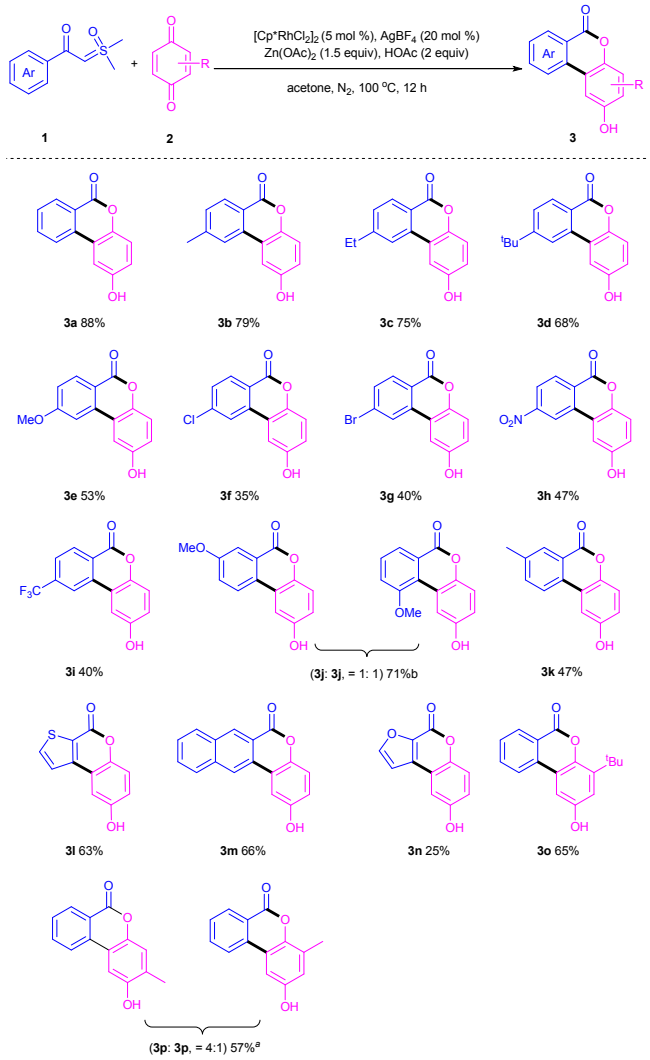
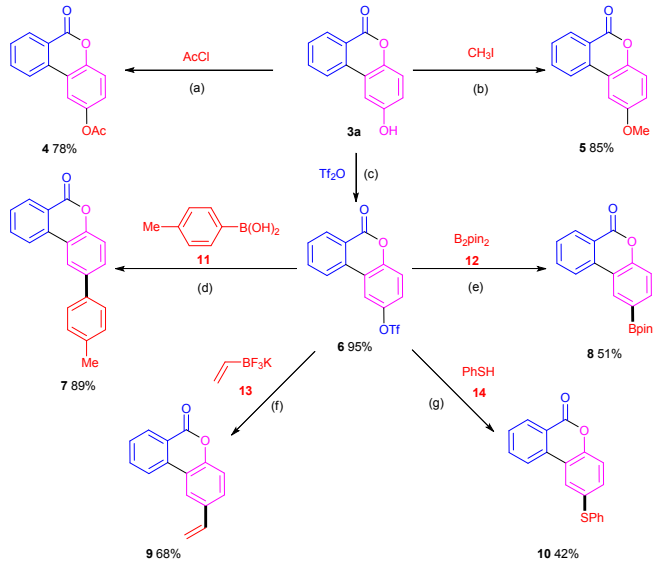


Figure 1. The substrates scope of sulfoxonium ylides and benzoquinones. Reaction conditions: sulfoxonium ylides **1** (0.15 mmol), benzoquinone **2** (0.3 mmol), $[Cp^*RhCl_2]_2$ (5 mol %), $AgBF_4$ (20 mol %), $Zn(OAc)_2$ (0.225 mmol), AcOH (0.3 mmol), acetone (2 mL), 12 h, in a sealed Schlenk tube under N_2 at 100 °C, unless otherwise noted. [a] determined by ^{1}H NMR.

Having established the optimized reaction conditions, firstly, the scope and limitation of sulfoxonium ylides were investigated, as summarized in Figure 1. As expected, the substituted sulfoxonium ylides proceeded smoothly with

benzoquinone **2a** to generate the corresponding 2-hydroxy-6H-benzo[*c*]chromen-6-ones in moderate to good yields. The electronic properties of the substituents on the phenyl ring of sulfoxonium ylides had profound effect on the reaction efficiency. For example, the substrates bearing electron-donating groups worked well in good yields (**3b**-**3e**, 53%-79%). However, for substrates bearing electron-withdrawing groups, the desired products were isolated in lower yields (**3f**-**3i**, 35%-47%). Fortunately, the reaction was applicable for *meta*-methyl sulfoxonium ylides (**3k**, 47%). However, *meta*-methoxy analogous resulted in two isomers **3j** and **3j'** (1/1, 71%). Notably, some functional groups, such as methyl (**3b**, 79%; **3k**, 70%), chloro (**3f**, 35%), bromo (**3g**, 40%), and nitro (**3h**, 47%), which were potential handles for further functionalization, all survived well in these reactions. Importantly, replacing the phenyl with 2-thiophene, 2-naphthyl and 2-furan, products **3l**, **3m** and **3n** were isolated in 63%, 66% and 25% yields, respectively.

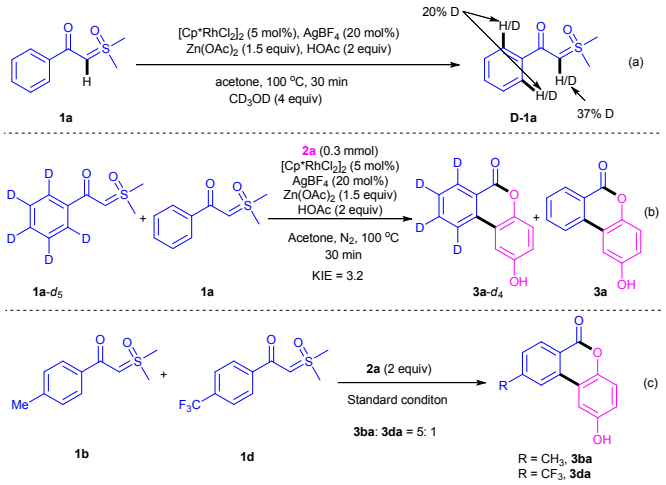
Next, functionalized benzoquinones were also investigated under the optimized reaction conditions. Interestingly, in the case of 2-(*tert*-butyl)cyclohexa-2,5-diene-1,4-dione, the corresponding product **3o** was isolated in 65% yield as solely product. However, for 2-methylcyclohexa-2,5-diene-1,4-dione, the regioselective isomers **3p** and **3p'** were isolated in 57% total yield and **3p'** was favored (3-methyl/5-methyl = 1/4).



Scheme 2. The further transformation of 2-hydroxy-6*H*-benzo[*c*]chromen-6-one **3a**. Reaction conditions: (a) pyridine, acetyl chloride, DCM; (b) **3a**, K_2CO_3, CH_3I, acetone, 35 °C; (c) **3a**, Tf_2O, Et_3N, 0 °C to rt; (d) **11**, $Pd(PPh_3)_4$, K_3PO_4, KBr, 1,4-dioxane, 85 °C, N_2; (e) **12**, $Pd(dppf)Cl_2$, KOAc, 1,4-dioxane, 110 °C, N_2; (f) **13**, $Pd(PPh_3)_2Cl_2$, Cs_2CO_3, THF/H_2O = 9/1, 90 °C, N_2; (g) $Pd_2(dba)_3$, Xantphos, PhSH, DIPEA, dioxane, 110 °C, N_2.

To increase the practicability of this procedure, the further transformation of 2-hydroxy-6H-benzo[*c*]chromen-6-one **3a** was studied. As shown in Scheme 2, in the presence of acetyl chloride, CH_3I or Tf_2O, the *para*-phenolic hydroxy group in **3a** was converted into its acetylated (**4**, 78%), methylated (**5**, 85%) or triflated (**6**, 95%) derivatives facilely. Additionally, some typical cross-coupling reaction of **6** have been tested, and *para*-arylated (**7**, 89%), Bpin (**8**, 51%), vinyl (**9**, 68%), phenylthiol (**10**, 42%) derivatives were isolated in acceptable efficiency.

More control experiments were conducted to get some insights into this transformation. As shown in Scheme 3, firstly, benzoy sulfoxonium ylides **1a** was treated by 4 equivalents of CD_3OD under the standard conditions (Scheme 3a). This reaction led to 20% of deuterium incorporation at the C2 position of D-**1a** demonstrated that C–H activation step was reversible. (Figure S1, Supporting Information). Moreover, a competitive reaction between **1a** and **1a**-d_5 with **2a** was carried out. From this reaction, an intermolecular kinetic isotopic effect value (K_H/K_D) of 3.2 was determined (Figure S2, Supporting Information). This result indicated that the cleavage of the C–H bond might be involved in the rate-limiting step of this reaction (Scheme 3b). Furthermore, the competitive experiment of **1b** and **1d** under the standard conditions, resulting in the formation of **3ba** and **3da** with the molar ratio of 5/1 (Figure S3, Supporting Information), indicating the electron-donating group on the phenyl ring of benzoyl sulfoxonium ylides was beneficial for this transformation (Scheme 3c).



Scheme 3. Control experiments

On the basis of the aforementioned results and some relative previous works,[10] a tentative mechanism is outlined in Scheme S1 (For details, please see SI). Firstly, the dimeric precursor $[Cp^*RhCl_2]_2$ converts to cationic species **A** in the presence of $AgBF_4$ and $Zn(OAc)_2$.[19] Then, the cationic Rh^{III} catalyst **A** reacts with **1a** proceeding with C–H cleavage leading to a five-membered rhodacycle intermediate **B**. Subsequently, coordination of the benzoquinone **2a** to the Rh(III) generates the intermediate **C**, which undergoes migratory insertion into the incipient Rh–C bond to form seven-membered rhodacycle **D**. Protonolysis and aromatization of intermediate **D** delivers intermediate **E** concomitantly and regenerates the catalyst Cp^*RhX_2. Finally, metal or acid catalyzed intramolecular nucleophilic attack furnishes the cyclization toward intermediate **F**, which converts to the final product **3a**

whereby the releasing of Corey's ylide **G** (For details, please see SI).[20]

Conclusions

In conclusion, we have developed a novel and facile rhodium(III)-catalyzed the carbonyl in sulfoxonium ylides assisted *ortho*- C−H functionalization of sulfoxonium ylides followed by intramolecular annulation with hydroquinones. This protocol leads to the efficient formation of 2-hydroxy-6*H*-benzo[*c*]chromen-6-one derivatives, proceeding with the cleavage of C(O)−C bond in sulfoxonium ylides where the carbonyl in sulfoxonium ylides served as chelation group and sulfoxonium ylides served as the aroyl source. This protocol featured with high chemo-selectivity and functional group tolerance.

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Conflicts of interest

There are no conflicts to declare.

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