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# Sequentially Pd/Cu-catalyzed Alkynylation-Oxidation Synthesis of 1,2-Diketones and Consecutive One-Pot Generation of Quinoxalines

Patrik Niesobski,[a] Ivette Santana Martínez,[a] Sebastian Kustosz,[a] and Thomas J. J. Müller*[a]

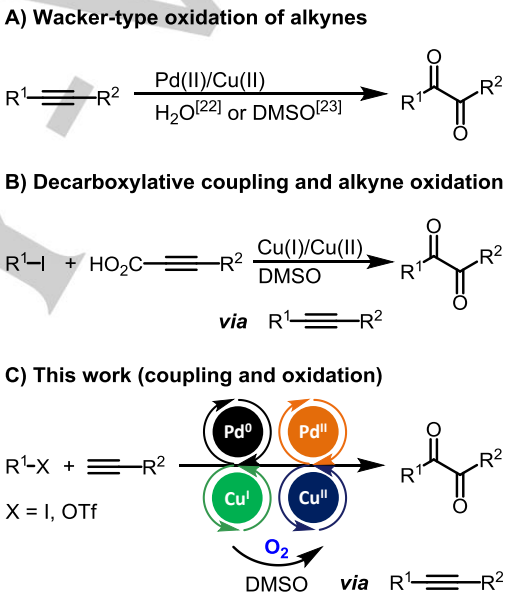
Dedication ((optional))

**Abstract:** We report a simple and efficient one-pot synthesis of 1,2-diketones by concatenation of two Pd/Cu-catalyzed processes: Pd(0)/Cu(I)-catalyzed Sonogashira coupling of terminal alkynes with aryl (pseudo)halides furnishes internal alkynes, which are directly transformed by Pd(II)/Cu(II)-catalyzed Wacker-type oxidation with DMSO and oxygen as dual oxidants to furnish 1,2-diketones. With this efficient, catalyst economical process, various aryl iodides and triflates are efficiently transformed in high yields into symmetrically and unsymmetrically substituted 1,2-diketones with various functional groups. This process can be readily extended to a consecutive one-pot synthesis of quinoxalines in a diversity-oriented fashion.

## Introduction

Diaryl 1,2-diketones, also known as benzil derivatives, are very important structural moieties in natural products,[1] biologically active compounds, such as antitumor agents,[2] as photoinitiators in radical polymerization,[3] and acid corrosion inhibitors of mild steel.[4] Moreover, 1,2-dicarbonyl derivatives can be broadly utilized as building blocks for the synthesis of complex and biologically active heterocyclic compounds, for instance quinoxalines, imidazoles and oxazoles.[5]

Due to the increasing interest in 1,2-diketones in recent years, many synthetic protocols for their preparation have been reported. Among classical syntheses, e.g. the oxidation of benzoin[6] or hydrobenzoin,[7] and several other methods,[8] 1,2-diketones can be very easily and efficiently prepared from alkynes,[9] which, in turn, are readily accessible by Sonogashira coupling.[10] Besides inorganic reagents such as iodine,[11] potassium permanganate,[12] sulfur trioxide,[13] potassium peroxymonosulfate,[14] and cerium ammonium nitrate (CAN),[15] diarylalkynes can be oxidized by palladium,[16] copper,[17] iron,[18] ruthenium[19] or gold[20] catalysts with oxidants. However, these methods are suffering from several drawbacks with respect to toxicity, harsh conditions, high loadings of expensive metal catalysts and the preparation and purification of starting materials. The Wacker-type oxidation[21] - a bimetallic Pd(II) and Cu(II) catalysis - of alkynes with $H_2O$[22] or DMSO[23] as a source for oxygen is a very efficient method (Scheme 1A) and has several advantages: the reaction proceeds without strong oxidant, under mild and neutral conditions, and with clean conversion in high efficiency. Nevertheless, these methods have some drawbacks, such as starting materials' preparation and relatively high catalyst loading.




**Scheme 1.** Synthesis of 1,2-diketones from internal alkynes as starting material respectively intermediate.

Recently, an efficient one-pot synthesis of diaryl 1,2-diketones from aryl iodides and arylalkynyl carboxylic acids was reported using a Cu(I)/Cu(II) couple as the catalyst system (Scheme 1B).[24] This methodology combines decarboxylative coupling and subsequent oxidation of the resulting diarylalkynes without their isolation. Both processes are mediated by the copper catalyst couple. However, this reaction is limited to aryl iodides, needs aryl propiolic acids and a high catalyst loading.

Starting from terminal alkynes we developed sequentially metal-catalyzed multicomponent reactions, particularly for synthesizing heterocycles in a one-pot fashion.[25] As a key transformation, Sonogashira coupling readily gives an access to alkynes,[26] alkynones,[27] and butadiynes[28] as reactive functional groups that are directly transformed into heterocycles and functional materials.[29] As a consequence we now reasoned that in situ generation of internal alkynes could excellently be concatenated with their oxidation to benzil derivatives and, hence, a novel

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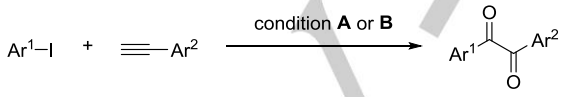
entry to multicomponent synthesis. We herein report a sequentially palladium/copper-catalyzed multicomponent synthesis of diaryl 1,2-diketones as a consecutive one-pot process (Scheme 1C). Conceptually this novel one-pot approach is grounded on the Pd(0)/Cu(I)-catalyzed Sonogashira coupling of aryl iodides or triflates with terminal alkynes, and without further catalyst addition the modulation into the Wacker-type Pd(II)/Cu(II)-system enabling the oxidation of the alkyne to the 1,2-dione with DMSO and oxygen via an ionic mechanistic pathway in a one-pot fashion.[23]

## Results and Discussion

Indeed, after a thorough optimization of this sequentially Pd-Cu-catalyzed one-pot coupling-oxidation process (for details see Supp Inf), iodobenzene (**1a**) and phenylacetylene (**2a**) can be transformed to benzil (**3a**) in the presence of catalytic amount of tetrakis(triphenylphosphane)-palladium(0) and CuI as well as a slight excess of triethylamine under an oxygen atmosphere and heating at 150 °C for 20 h. DMSO was used as a solvent or cosolvent and source of oxygen since no product was formed from tolane with $H_2O$ (see Table S1, Supp Inf). In the Sonogashira coupling step, in 1,4-dioxane the conversion is complete after 10 minutes at room temperature and after subsequent oxidation the benzil (**3a**) could be obtained in excellent yield of 93% (condition **A**, Table 1), whereas in DMSO the intermediate tolane is completely formed at 50 °C after 4 hours and subsequent oxidation furnished **3a** in 87% yield (condition **B**, Table 1). However, as for condition **A**, DMSO has to be added for the oxidation step.

For both optimized conditions **A** and **B** for the Sonogashira-oxidation sequence with aryl iodides **1** and alkynes **2** , the scope of the sequentially Pd-Cu-catalyzed *pseudo*-four-component synthesis of 1,2-diketones **3**, was screened and illustrated for 19 examples of benzil derivatives **3** that were obtained in 19–93 % yield. As summarized in Table 1, various substituted iodo benzene derivatives **1** were well tolerated in the reaction.

**Table 1.** Scope of the coupling-oxidation sequence (condition **A** or **B**) with aryl iodides **1** and alkynes **2** furnishing 1,2 diketones **3**.

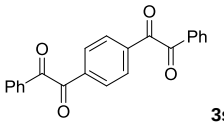



**1** **2** **3**

condition **A**: 2 mol% $Pd(PPh_3)_4$, 4 mol% CuI, $NEt_3$ (1.1 eq.), 1,4-dioxane, rt, 10 min
**then:** DMSO, 150 °C, 20 h, $O_2$

condition **B**: 2 mol% $Pd(PPh_3)_4$, 4 mol% CuI, $NEt_3$ (1.1 eq.), DMSO, 50 °C, 4 h
**then:** 150 °C, 20 h, $O_2$

| Entry | **1**/$Ar^1$ | **2**/$Ar^2$ | **3** | Yield [%][a] condition **A**[b] | condition **B**[c] |
|---|---|---|---|---|---|
| 1 | **1a**/Ph | **2a**/Ph | **3a** | 93 | 87 |
| 2 | **1b**/4-$O_2NC_6H_4$ | **2a**/Ph | **3b** | 72 | 84 |
| 3 | **1c**/4-$NCC_6H_4$ | **2a**/Ph | **3c** | 69 | 63 |
| 4 | **1d**/4-$OHCC_6H_4$ | **2a**/Ph | **3d** | 62 | 69 |
| 5 | **1e**/4-$ClC_6H_4$ | **2a**/Ph | **3e** | 83 | 87 |
| 6 | **1f**/4-$BrC_6H_4$ | **2a**/Ph | **3f** | 71 | - |
| 7 | **1g**/4-$MeC_6H_4$ | **2a**/Ph | **3g** | 69 | 64 |
| 8 | **1a**/Ph | **2b**/4-$MeOC_6H_4$ | **3h** | 78 | 87 |
| 9 | **1a**/Ph | **2c**/4-$PhC_6H_4$ | **3i** | 87 | - |
| 10 | **1h**/2-$MeC_6H_4$ | **2a**/Ph | **3j** | 51 | 70 |
| 11 | **1a**/Ph | **2d**/3-$FC_6H_4$ | **3k** | 83 | 86 |
| 12 | **1a**/Ph | **2e**/4-pyridyl | **3l** | 19 | 26 |
| 13 | **1i**/2-thiophenyl | **2a**/Ph | **3m** | 31 | -[d] |
| 14 | **1j**/3-quinolinyl | **2a**/Ph | **3n** | - | 66 |
| 15 | **1b**/4-$O_2NC_6H_4$ | **2f**/4-$O_2NC_6H_4$ | **3o** | 70 | 77 |
| 16 | **1c**/4-$NCC_6H_4$ | **2g**/4-$NCC_6H_4$ | **3p** | - | 54 |

| | | | | | |
|---|---|---|---|---|---|
| 17 | **1k**/4-$MeOC_6H_4$ | **2b**/4-$MeOC_6H_4$ | **3q** | 78 | 80 |
| 18 | **1b**/4-$O_2NC_6H_4$ | **2b**/4-$MeOC_6H_4$ | **3r** | 76 | 85 |
| 19[d] | **1a**/Ph | 1,4-(diethynyl)benzene (**2h**) |  **3s** | - | 62 |

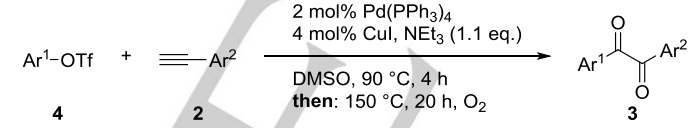
[a] Isolated yield after chromatography on silica gel. [b] Reaction conditions **A**: **1** (0.50 mmol), **2** (0.55 mmol), $NEt_3$ (0.55 mmol), $Pd(PPh_3)_4$ (2 mol%), CuI (4 mol%), 1,4-dioxane (0.5 mL), rt, 10 min. **Then**: DMSO (4.5 mL), 150 °C, 20 h, $O_2$. [c] Reaction conditions **B**: **1** (0.50 mmol), **2** (0.55 mmol), $NEt_3$ (0.55 mmol), $Pd(PPh_3)_4$ (2 mol%), CuI (4 mol%), DMSO (5.0 mL), 50 °C, 4 h. **Then**: 150 °C, 20 h, $O_2$. [d] For compound **2h** 0.28 mmol were employed.

Aryl iodides **1** are equally tolerated for electron-withdrawing groups (Table 1, entries 2-6, 15, 16 and 18) as well as for electron-donating groups (Table 1, entries 7, 10 and 17). Arylacetylenes **2** with electron-withdrawing groups (Table 1, entries 11, 15 and 16), and electron-releasing groups (Table 1, entries 8, 17 and 18) as well as biphenyl acetylene (Table 1, entry 9) can be successfully employed. 1,4-Diethynylbenzene (**2h**) was transformed into the corresponding tetraketone in moderate yield (entry 19). 4-Pyridyl- and 2-thienyl derivatives were obtained in low yields (Table 1, entries 12 and 13), whereas for 3-iodoquinoline (**1j**) the corresponding 1,2-diketone was isolated in moderate yield (Table 1, entry 14). In general the yields for condition **B** are slightly higher in comparison to condition **A**. However, all attempts to transform aliphatic alkynes such as 1-hexyne, 3-butyne-1-ol, ethyl propiolate and trimethylsilyl acetylene failed so far.

Alternative starting materials for aryl iodides were also considered. With bromobenzene and phenylacetylene (**2a**), decomposition was observed and benzil (**3a**) could only be obtained in 41% yield (see Table S2, Supp Inf).

Aryl triflates, which can be readily prepared from the corresponding phenols, have been tested. Fortunately, phenyl triflate (**4a**) can be converted with phenylacetylene (**2a**) into tolane in DMSO at 90 °C in 4 h and then oxidized under the established conditions (150 °C, 20 h, $O_2$) furnishing benzil (**3a**) in an excellent yield of 94% (condition **C**, Table 2, entry 1). With these optimized conditions for the Sonogashira coupling-oxidation sequence with aryl triflates **4**, we screened the scope of the sequentially Pd-Cu-catalyzed *pseudo*-four-component synthesis of 1,2-diketones **3**, where the triflates **4** and alkynes **2** were varied. After isolation and purification, 12 examples of benzyl derivatives **3** were obtained in 12–95 % yield (Table 2).

**Table 2.** Scope of the coupling-oxidation sequence (condition **C**) with aryl triflates **4** and alkynes **2** furnishing 1,2 diketones **3**.[a]



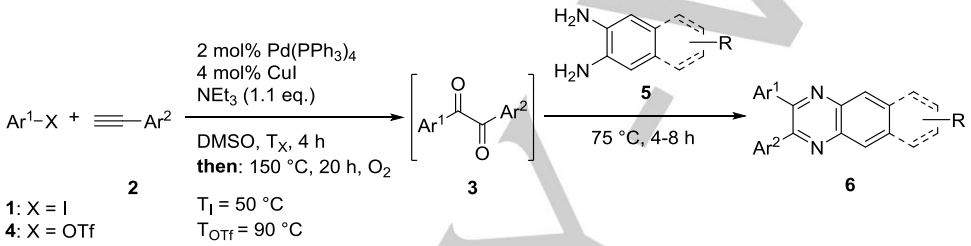

**4** **2** **3**

| Entry | **4**/$Ar^1$ | **2**/$Ar^2$ | **3** | Yield [%][b] |
|---|---|---|---|---|
| 1 | **4a**/Ph | **2a**/Ph | **3a** | 94 |
| 2 | **4b**/4-$O_2NC_6H_4$ | **2a**/Ph | **3b** | 91 |
| 3 | **4c**/4-$NCC_6H_4$ | **2a**/Ph | **3c** | 12 |
| 4 | **4d**/4-$ClC_6H_4$ | **2a**/Ph | **3e** | 95 |
| 5 | **4e**/4-$MeC_6H_4$ | **2a**/Ph | **3g** | 79 |
| 6 | **4a**/Ph | **2b**/4-$MeOC_6H_4$ | **3h** | 70 |
| 7 | **4a**/Ph | **2c**/3-$FC_6H_4$ | **3k** | 92 |
| 8 | **4a**/Ph | **2d**/4-pyridyl | **3l** | 45 |
| 9 | **4b**/4-$O_2NC_6H_4$ | **2e**/4-$O_2NC_6H_4$ | **3o** | 72 |
| 10 | **4f**/4-$MeOC_6H_4$ | **2b**/4-$MeOC_6H_4$ | **3q** | 45 |
| 11 | **4b**/4-$O_2NC_6H_4$ | **2b**/4-$MeOC_6H_4$ | **3r** | 84 |
| 12 | **4a**/Ph | 1,4-(diethynyl)benzene (**2h**) | **3s** | 58 |
| 13[c] | **4g**/Ph | **2a**/Ph | **3a** | 90 |

[a] Reaction conditions **C**: **4** (0.50 mmol), **2** (0.55 mmol), $NEt_3$ (0.55 mmol), $Pd(PPh_3)_4$ (2 mol%), CuI (4 mol%), DMSO (2.5 mL), 90 °C, 4 h. **Then**: 150 °C, 20 h, $O_2$. [b] Isolated yield after chromatography on silica gel. [c] 0.50 mmol of phenylnonaflate (**4g**).

The aryl triflates **4** substituted with electron-withdrawing groups (Table 2, entries 2, 4, 9 and 11) as well as electron-donating groups (Table 2, entries 5 and 10) gave the corresponding 1,2-diketones **3** in moderate to excellent yields. However, in the case of *p*-cyano-substituted phenyl triflate **4c**, the product could only be isolated in very poor 12% yield (entry 3). Arylacetylenes with electron-withdrawing groups (Table 2, entries 7 and 9) and electron-donating group (Table 2, entries 6, 10 and 11) are well tolerated. 1,4-Diethynylbenzene (**2h**) could be transformed to the corresponding tetraketone in a moderate yield (Table 2, entry 12). Compared to methods **A** and **B** with iodobenzene (**1a**) (Table 1, entry 12), the 4-pyridyl-substituted alkyne **2d** reacted with phenyltriflate (**4a**) and the product was obtained in a moderate yield of 45% (entry 8). Nonaflates (nonafluorobutanesulfonates) as $C_4$ homologues of triflates have also been used as a coupling partner.[30] Under the same conditions as for aryl triflates, benzil (**3a**) could be obtained from phenylnonaflate (**4g**) and phenylacetylene (**2a**) in an excellent yield of 90% (entry 13). For illustration of the utility of this novel sequentially Pd/Cu-catalyzed alkynylation-oxidation process a consecutive one-pot coupling-oxidation-cyclocondensation synthesis was conceived. Starting from aryl iodides **1** or triflates **4** and arylacetylenes **2** the generated benzils were reacted in the same reaction vessel by addition of 1,2-diamino derivatives **5** at 75 °C for after 4 to 8 h to give quinoxalines **6**, which have recently received considerable interest as emission solvatochromic materials[31] and aggregation-induced emissive chromophores.[32] After isolation and purification 12 different quinoxalines **6** were obtained in 42–87% yield (Table 3), where various substituted aryl iodides **1** or triflates **4** and *ortho*-phenylene diamines **5** were well tolerated in the reaction.

**Table 3.** Scope of the coupling-oxidation-cyclization sequence (via condition **B** or **C**) with aryl iodides **1** or aryl triflates **4**, alkynes **2** and 1,2-diamino derivatives **5** furnishing quinoxalines **6**.




| Entry | Substrate/$Ar^1$/X | **2**/$Ar^2$ | 1,2-Diamino benzene derivative **5** | **6** | Yield [%][a] |
|---|---|---|---|---|---|
| 1[b] | **1a**/Ph/I | **2a**/Ph | *o*-phenylenediamine (**5a**) | **6a** | 82 |
| 2[c] | **4a**/Ph/OTf | **2a**/Ph | *o*-phenylenediamine (**5a**) | **6a** | 85 |
| 3[c] | **4b**/4-$O_2NC_6H_4$/OTf | **2f**/4-$O_2NC_6H_4$ | *o*-phenylenediamine (**5a**) | **6b** | 62 |
| 4[b] | **1c**/4-$NCC_6H_4$/I | **2g**/4-$NCC_6H_4$ | *o*-phenylenediamine (**5a**) | **6c** | 45 |
| 5[c] | **4e**/4-$MeC_6H_4$/OTf | **2i**/4-$MeC_6H_4$ | *o*-phenylenediamine (**5a**) | **6d** | 42 |
| 6[b] | **1k**/4-$MeOC_6H_4$/I | **2b**/4-$MeOC_6H_4$ | *o*-phenylenediamine (**5a**) | **6e** | 71 |
| 7[b] | **1b**/4-$O_2NC_6H_4$/I | **2b**/4-$MeOC_6H_4$ | *o*-phenylenediamine (**5a**) | **6f** | 78 |
| 8[c] | **4d**/4-$ClC_6H_4$/OTf | **2d**/3-$FC_6H_4$ | *o*-phenylenediamine (**5a**) | **6g** | 87 |
| 9[c] | **4b**/4-$O_2NC_6H_4$/OTf | **2f**/4-$O_2NC_6H_4$ | 4,5-dichloro-*o*-phenylenediamine (**5b**) | **6h** | 79 |
| 10[b] | **1k**/4-$MeOC_6H_4$/I | **2b**/4-$MeOC_6H_4$ | 4,5-dichloro-*o*-phenylenediamine (**5b**) | **6i** | 76 |
| 11[b] | **1a**/Ph/I | **2a**/Ph | 2,3-diaminonaphthalene (**5c**) | **6j** | 76 |
| 12[c] | **4a**/Ph/OTf | **2a**/Ph | 2,3-diaminonaphthalene (**5c**) | **6j** | 62 |
| 13[c] | **4b**/4-$O_2NC_6H_4$/OTf | **2f**/4-$O_2NC_6H_4$ | 2,3-diaminonaphthalene (**5c**) | **6k** | 66 |
| 14[b,d] | **1k**/4-$MeOC_6H_4$/I | **2b**/4-$MeOC_6H_4$ | 2,3-diaminonaphthalene (**5c**) | **6l** | 78 |

[a] Isolated yield after chromatography on silica gel. [b] Reaction conditions: **1** (0.50 mmol), **2** (0.55 mmol), $NEt_3$ (0. 55 mmol), $Pd(PPh_3)_4$ (2 mol%), CuI (4 mol%), DMSO (5.0 mL), 50 °C, 4 h. **Then**: 150 °C, 20 h, $O_2$. **Then**: **5** (0.75 mmol), 75 °C, 4 h. [c] Reaction conditions: **4** (0.50 mmol), **2** (0.55 mmol), $NEt_3$ (0.55 mmol), $Pd(PPh_3)_4$ (2 mol%), CuI (4 mol%), DMSO (2.5 mL), 90 °C, 4 h. **Then**: 150 °C, 20 h, $O_2$. **Then**: **5** (0.75 mmol), 75 °C, 4 h. [d] The cyclization step was performed in 8 h.

## Conclusions

In summary, we have successfully developed a novel and facile one-pot synthesis of diaryl 1,2-diketones from aryl iodides or triflates and terminal alkynes, involving two distinct Pd/Cu-catalyzed steps upon efficiently utilizing the bimetallic catalyst system. First, tolanes are formed by Pd(0)/Cu(I)-catalyzed Sonogashira coupling before 1,2-diketones are subsequently formed by Pd(II)/Cu(II)-catalyzed Wacker-type oxidation with DMSO and oxygen as dual oxidants The desired title compounds are obtained in good yields and many functional groups are well tolerated. In addition, quinoxalines can be obtained in a consecutive one-pot fashion by subsequent addition of 1,2-diamino phenylene derivatives. This versatile entry to benzils can be readily extended to other consecutive multicomponent syntheses of heterocycles that are currently underway as mechanistic studies of the oxidation step.

## Experimental Section

**Typical procedure for the synthesis of compound 3a with iodobenzene (1a)**

Tetrakis(triphenylphosphane)palladium(0) (11.6 mg, 10.0 µmol, 2.00 mol%) and copper(I)iodide (3.80 mg, 20.0 µmol, 4.00 mol%) were placed in a Schlenk tube and the atmosphere was evacuated and replaced by argon three times. Then, iodobenzene (102 mg, 500 µmol, 1.00 equiv), phenylacetylene (56.2 mg, 550 µmol, 1.10 equivs) and 1,4-dioxane (0.5 mL) were added. After addition of triethylamine (55.7 mg, 550 µmol, 1.10 equivs), the reaction mixture was stirred for 10 min at room temperature. Then, the argon atmosphere was replaced by oxygen by using a tube before DMSO (4.5 mL) was added and the mixture stirred at 150 °C under oxygen atmosphere for 20 h. After cooling to room temperature, the reaction mixture was extracted with ethyl acetate (25 mL) and aqueous sodium sulfite solution (100 mM, 4 x 25 mL). The aqueous layer was extracted again with ethyl acetate (3 × 25 ml) before the combined organic layers were washed with distillated water (3 x 25 mL) and brine (25 mL) and dried with anhydrous sodium sulfate. After removal of the drying agent by filtration and solvent by reduced pressure, the product mixture was adsorbed onto Celite® and purified by column chromatography on silica gel to afford 3a (98.0 mg, 466 µmol, 93% yield) as a yellow solid; mp 94–95 °C. $^1$H NMR ($CDCl_3$, 300 MHz): $\delta$ 7.52 (t, $J$ = 7.6 Hz, 4 H), 7.67 (t, $J$ = 7.4 Hz, 2 H), 7.95–8.01 (m, 4 H).$^{13}$C NMR ($CDCl_3$, 75 MHz): $\delta$ 129.2 (CH), 130.1 (CH), 133.1 ($C_{quat}$) ,135.0 (CH), 194.7 ($C_{quat}$). MS (GC-MS, m/z (%)): 210 ([M]$^+$, 2), 105 ([$C_7H_5O$]$^+$, 100), 77 ([$C_6H_5$]$^+$, 58), 51 ([$C_4H_3$]$^+$, 25).

**Typical procedure for the synthesis of compound 3b with 4-nitrophenyl triflate (4b)**

Tetrakis(triphenylphosphane)palladium(0) (11.6 mg, 10.0 µmol, 2.00 mol%) and copper(I)iodide (3.80 mg, 20.0 µmol, 4.00 mol%) were placed in a Schlenk tube and the atmosphere was evacuated and replaced by argon three times. Then, 4-nitrophenyl triflate (136 mg, 500 µmol, 1.00 equiv), phenylacetylene (56.2 mg, 550 µmol, 1.10 equivs) and DMSO (2.5 mL) were added. After addition of triethylamine (55.7 mg, 550 µmol, 1.10 equivs), the reaction mixture was stirred for 4 hours at 90 °C. Then at room temperature, the argon atmosphere was replaced by oxygen by using a tube and the mixture stirred at 150 °C under oxygen atmosphere for 20 h. After cooling to room temperature, the reaction mixture was extracted with ethyl acetate (25 mL) and aqueous sodium sulfite solution (100 mM, 4 x 25 mL). The aqueous layer was extracted again with ethyl acetate (3 × 25 ml) before the combined organic layers were washed with distillated water (3 x 25 mL) and brine (25 mL) and dried with anhydrous sodium sulfate. After removal of the drying agent by filtration and solvent by reduced pressure, the product mixture was adsorbed onto Celite® and purified by column chromatography on silica gel to afford 3b (116 mg, 454 µmol, 91% yield) as a yellow solid; mp 139 °C. $^1$H NMR ($CDCl_3$, 300 MHz): $\delta$ 8.36 (d, $J$ = 9.0 Hz, 2 H), 8.17 (d, $J$ = 9.0 Hz, 2 H), 7.95–8.00 (m, 2 H), 7.71 (t, $J$ = 7.4 Hz, 1 H), 7.55 (t, $J$ = 7.7 Hz, 2 H). $^{13}$C NMR ($CDCl_3$, 75 MHz): $\delta$ 124.3 (CH), 129.4 (CH), 130.2 (CH), 131.1 (CH), 132.5 ($C_{quat}$), 135.6 (CH), 137.5 ($C_{quat}$), 151.3 ($C_{quat}$), 192.2 ($C_{quat}$), 193.0 ($C_{quat}$). MS (GC-MS, m/z (%)): 150 ([$C_7H_4NO_3$]$^+$, 2) 105 ([$C_7H_5O$]$^+$, 100), 77 ([$C_6H_5$]$^+$, 48), 51 ([$C_4H_3$]$^+$, 13).

**Typical procedure for the synthesis of compound 6g**

Tetrakis(triphenylphosphane)palladium(0) (11.6 mg, 10.0 µmol, 2.00 mol%) and copper(I)iodide (3.80 mg, 20.0 µmol, 4.00 mol%) were placed in a Schlenk tube and the atmosphere was evacuated and replaced by argon three times. Then, 4-chlorophenyl triflate (130 mg, 500 µmol, 1.00 equiv), 1-ethynyl-3-fluorobenzene (66.1 mg, 550 µmol, 1.10 equivs) and DMSO (2.5 mL) were added. After addition of triethylamine (55.7 mg, 550 µmol, 1.10 equivs), the reaction mixture was stirred for 4 hours at 90 °C. Then at room temperature, the argon atmosphere was replaced by oxygen by using a tube and the mixture stirred at 150 °C under oxygen atmosphere for 20 h. At room temperature, 1,2-diaminobenzene (81.1 mg, 750 µmol, 1.50 equivs) was added and stirred at 75 °C under air atmosphere to complete conversion (4 h, TLC control). After cooling to room temperature, the reaction mixture was extracted with ethyl acetate (25 mL) and aqueous sodium sulfite solution (100 mM, 4 x 25 mL). The aqueous layer was extracted again with ethyl acetate (3 × 25 ml) before the combined organic layers were washed with distillated water (3 x 25 mL) and brine (25 mL) and dried with anhydrous sodium sulfate. After removal of the drying agent by filtration and solvent by reduced pressure, the product mixture was adsorbed onto Celite® and purified by column chromatography on silica gel to afford 6g (146 mg, 437 µmol, 87% yield) as a yellow solid; mp 125–127 °C. $^1$H NMR (acetone-$d_6$, 300 MHz): $\delta$ 7.17–7.26 (m, 1 H), 7.3–7.47 (m, 5 H), 7.59 (d, $J$ = 8.7 Hz, 2 H), 7.87–7.91 (m, 2 H), 8.12–8.17 (m, 2 H). $^{13}$C NMR (acetone-$d_6$, 75 MHz): $\delta$ 116.5 (d, $J$(C, F) = 21.3 Hz, CH), 117.6 (d, $J$(C, F) = 22.9 Hz, CH), 127.0 (d, $J$(C, F) = 3.0 Hz, CH), 129.2 (CH), 130.1 (CH), 130.1 (CH), 130.9 (d, $J$(C, F) = 8.3 Hz, CH), 131.3 (CH), 131.4 (CH), 132.5 (CH), 135.6 ($C_{quat}$), 138.9 ($C_{quat}$), 142.1 (d, J(C, F) = 10.3 Hz, $C_{quat}$), 142.5 ($C_{quat}$), 142.6 ($C_{quat}$), 152.8 (d, J(C, F) = 2.3 Hz, $C_{quat}$), 153.0 ($C_{quat}$), 163.4 (d, J(C, F) = 244.5 Hz, $C_{quat}$). $^{19}$F NMR (Acetone-$d_6$, 565 MHz): $\delta$ -114.39. MS (GC-MS, m/z (%)): 334 ([M]$^+$, 100) 299 ([$C_{20}H_{12}FN_2$]$^+$, 46), 197 ([$C_{13}H_8FN$]$^+$, 32), 178 ([$C_{13}H_8N_3$]$^+$, 39), 102 ([$C_7H_4N_3$]$^+$, 15), 76 ([$C_6H_4$]$^+$, 68). IR (ATR): $\tilde{\nu}$ [cm$^{-1}$] 1538 (m), 1477 (m), 1341 (m), 1236 (m), 1092 (m), 993 (m), 856 (m), 837 (s), 795 (m), 764 (s), 748 (m), 715 (s), 681 (m). Anal. calcd. for $C_{20}H_{12}ClFN_2$ [334.8]: C 71.75, H 3.61, N 8.37; found: C 71.97, H 3.78, N 8.19.

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**Keywords:** one-pot catalysis • multicomponent reaction • Sonogashira coupling • oxidation • 1,2-diketones

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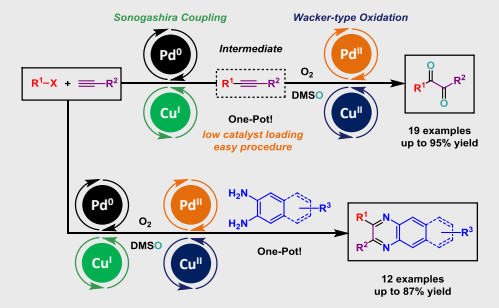
**Entry for the Table of Contents** (Please choose one layout)

Layout 1:

# COMMUNICATION

A sequentially Pd/Cu-catalyzed alkynylation-oxidation reaction furnishes 1,2-diketones in a one-pot fashion. This one-pot process can be successfully concatenated with a cyclocondensation to furnish a consecutive multicomponent synthesis of quinoxalines.




**One-pot catalysis***

*Patrik Niesobski, Ivette Santana Martínez, Sebastian Kustosz, and Thomas J. J. Müller**

***Page No. – Page No.***

**Sequentially Pd/Cu-catalyzed Alkynylation-Oxidation Synthesis of 1,2-Diketones and Consecutive One-Pot Generation of Quinoxalines**