EurJOC
European Journal of Organic Chemistry

A Journal of ChemPubSoc Europe

# Accepted Article

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**To be cited as:** *Eur. J. Org. Chem.* 10.1002/ejoc.201901536

**Link to VoR:** http://dx.doi.org/10.1002/ejoc.201901536

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FULL PAPER

Allylic Alkylation

# Palladium-Catalyzed Allylation of Cyclopropyl Acetylenes with Oxindoles to Construct 1,3-Dienes

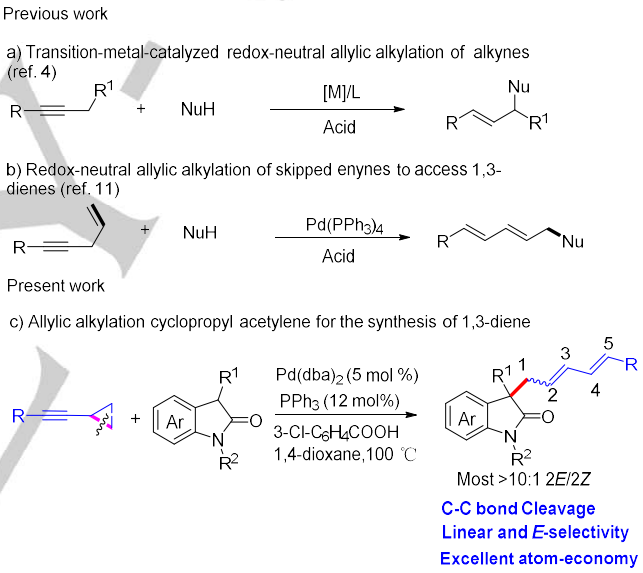
Chuan-Jun Lu,*[a] Xin Yu,[a] Yu-Ting Chen,[a] Qing-Bao Song,*[a] Zhen-Ping Yang,[a] Hong Wang[a]

**Abstract:** A novel palladium-catalyzed allylic alkylation of oxindoles with cyclopropyl acetylenes has been developed. Various 1,3-diene oxindole framework bearing a quaternary stereocenter at the C3 position were synthesized straightforwardly in good to excellent yields with high regio-, and stereoselectivities. The reaction exhibited high atom economy and good functional group tolerance.

## Introduction

Transition-metal-catalyzed allylic alkylation provides a powerful approach to construct C-C and C-heteroatom bonds in organic synthesis, which has allowed chemists to construct complex molecular frameworks of natural products and medicinal chemistry.[1] The treatment of allyl alcohol derivatives, such as acetates, carbonates, and halides, with nucleophiles in the presence of transition metals is a reliable approach for the synthesis of this class of compounds.[2] However, some unavoidable limitations of the method still exist with respect to the formation of stoichiometric valueless byproducts and prefunctionalization of substrates. Recently, the transition-metal-catalyzed redox-neutral allylic alkylation of internal or terminal alkynes in the presence of metal with acid catalyst as the co-catalyst has been described with excellent atom efficiency without any waste formation.[3] Several C-C and C-heteroatom bonds formation with these alkynes have been subsequently reported to establish linear or branched allylated compounds (Scheme 1, a)).[4]

Conjugated 1,3-dienes are attractive building blocks for medicinal and natural product synthesis and also participate in an increasing variety of useful transformations, including hydrofunctionalizations, ring-forming reactions, and polymerizations.[5] Although a number of synthetic methods, including cross-coupling,[6] eneyne metathesis,[7] C-H vinylation,[8] and allylic substitution[9] and others,[10] to build 1,3-dienes are currently available, those atom economy method to access 1,3-dienes remain only a few and still highly attractive. Recently, Yao and Lin have developed an elegant palladium-catalyzed redox-neutral allylic alkylation with unactivated skipped enynes to access a wide array of 1,3-dienes with high atom economy and good functional group tolerance (Scheme 1, b)).[11] Mechanistically, we were drawn to the possibility that cyclopropyl phenyl acetylene could provide a general system for building 1,3-dienes by the cleavage of C-C bond.[12,13] As part of our ongoing studies of allylation reaction of alkynes,[14] we report herein a palladium catalyzed allylic alkylation of oxindole with cyclopropyl acetylene for the synthesis of 1,3-diene oxindole framework bearing a quaternary stereocenter at the C3 position[15] with high regio-, and stereoselectivities in excellent atom economy (Scheme 1, c)).




**Scheme 1.** Redox-neutral allylic alkylation reaction of alkynes.

## Results and Discussion

To identify the optimized reaction conditions, we chose *N*-methyl-3-phenyloxindole **1a** and cyclopropyl phenyl acetylene **2a** as our pilot substrate. Fortunately, the reaction of **1a** with **2a** in the presence of 5 mol% of $Pd(PPh_3)_4$ and 1.0 equiv of 3-chlorobenzoic acid in 1.0 mL of anhydrous 1,4-dioxane at 100 ℃ under argon for 12 h, afforded the desired product **3aa** and **3aa'** in 87% total yield with good regio-, and stereoselectivity (*E*/*Z* = 9.1:1) (Table 1, entry 1). Sreening of palladium catalysts exhibited that the desired product could be obtained in good yields (82-95%), when $Pd(OAc)_2$, $Pd(dba)_2$ or $Pd_2(dba)_3$ was used as catalyst (Table 1, entries 2-4). While no product was obtained with $Pd(PPh_3)_2Cl_2$ as catalyst (Table 1, entry 5). Ligand examination showed that $PPh_3$ is the best ligand for this transformation, dppb, Xantphos and BINAP exhibited sharply reduced yield of **3aa** (Table 1, entries 6-8). Further screening of

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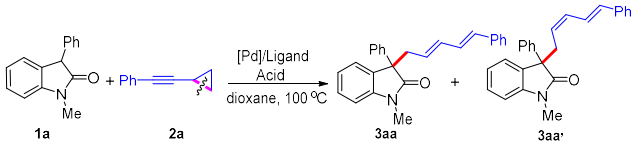
*Supporting information and ORCID(s) from the author(s) for this article are available on the WWW under https://doi.org/10.1002/ejoc.201901536R1.*

acids suggested that 3-chlorobenzoic acids remained the best result. Other acids such as 3-F-$C_6H_4CO_2H$, $C_6H_4CO_2H$, $CH_3CO_2H$ and TsOH showed inferior performance with respect to both product yields and ratios of **3aa/3aa'** (Table 1, entries 9-12). Moreover, both the yield and ratio can be slightly enhanced by lowering the concentration of reaction (Table 1, entry 13). In addition, there was subtle influence on outcome when catalytic amount of 3-Cl-$C_6H_4CO_2H$ was used as the co-catalyst (Table 1, entry 15). Above all, the model reaction conditions was chosen to be **1a** (0.2 mmol), **2a** (0.24 mmol), 3-Cl-$C_6H_4CO_2H$ (10 mol %), 5 mol% $Pd(dba)_2$, 12 mol% $PPh_3$ in 2.0 mL dioxane at 100 °C for 12 h (Table 1, entry 15).

**Table 1.** Optimization of reaction conditions[a]

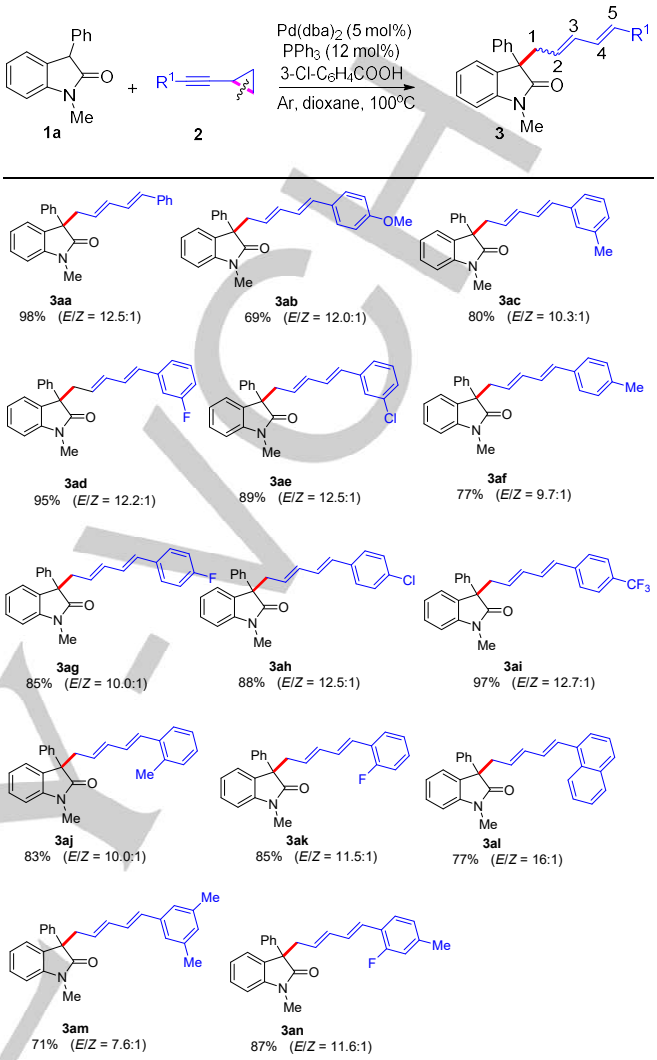



| Entry | Catalyst | Ligand | Additive | Yield[b] | **3aa**: **3aa'**[c] |
|---|---|---|---|---|---|
| 1 | $Pd(PPh_3)_4$ | / | 3-Cl-$C_6H_4CO_2H$ | 87 | 9.1:1 |
| 2 | $Pd(OAc)_2$ | $PPh_3$ | 3-Cl-$C_6H_4CO_2H$ | 86 | 10:1 |
| 3 | $Pd_2(dba)_3$ | $PPh_3$ | 3-Cl-$C_6H_4CO_2H$ | 95 | 10:1 |
| 4 | $Pd(dba)_2$ | $PPh_3$ | 3-Cl-$C_6H_4CO_2H$ | 93 | 11.2:1 |
| 5 | $Pd(PPh_3)_2Cl_2$ | $PPh_3$ | 3-Cl-$C_6H_4CO_2H$ | 0 | / |
| 6 | $Pd(dba)_2$ | dppb | 3-Cl-$C_6H_4CO_2H$ | 45 | 7.7:1 |
| 7 | $Pd(dba)_2$ | Xantphos | 3-Cl-$C_6H_4CO_2H$ | 35 | 9.1:1 |
| 8 | $Pd(dba)_2$ | BINAP | 3-Cl-$C_6H_4CO_2H$ | 37 | 6.7:1 |
| 9 | $Pd(dba)_2$ | $PPh_3$ | 3-F-$C_6H_4CO_2H$ | 85 | 8.4:1 |
| 10 | $Pd(dba)_2$ | $PPh_3$ | $CH_3CO_2H$ | 78 | 8.4:1 |
| 11 | $Pd(dba)_2$ | $PPh_3$ | $C_6H_4CO_2H$ | 76 | 9.1:1 |
| 12 | $Pd(dba)_2$ | $PPh_3$ | TsOH | 3 | / |
| 13[d] | $Pd(dba)_2$ | $PPh_3$ | 3-Cl-$C_6H_4CO_2H$ | 98 | 12.5:1 |
| 14[e] | $Pd(dba)_2$ | $PPh_3$ | 3-Cl-$C_6H_4CO_2H$ | 88 | 11.2:1 |
| 15[d,f] | $Pd(dba)_2$ | $PPh_3$ | 3-Cl-$C_6H_4CO_2H$ | 97 | 12.5:1 |

[a] Reaction conditions: **1a** (0.2 mmol), **2a** (0.24 mmol), 3-Cl-$C_6H_4CO_2H$ (1.0 equiv.), 5 mol% Pd catalyst, 12 mol% ligand in 1.0 mL dioxane at 100 oC for 12 h. [b] Isolated yields and the yields are reported as a mixture of 3aa (E) and 3aa' (Z) isomers. [c] The ratios were determined by $^1H$ NMR. [d] In 2.0 mL dioxane. [e] In 0.5 mL dioxane. [f] 10 mol % 3-Cl-$C_6H_4CO_2H$ was used.

With the optimized conditions in hand, we then explored the substrate scope of the alkynes and the results are summarized in Table 2. Different aromatic-substituted cyclopropylethynyl were subjected to the reaction to afford the 1,3-dienes products. The reactions worked well over different aryl substituents bearing both electron-donating groups (−OMe, −Me) and electron-withdrawing groups (−$CF_3$, −F, −Cl) on the phenyl group, delivering the corresponding linear allylic products in high regio- and stereoselectivities (**3aa**-**3ak**). Generally, the alkynes having the electron-withdrawing groups, gave better yields than the ones with electron-donating groups (**3ab** vs **3ai**, **3ad** vs **3ac**). Ortho-substituted alkynes also showed good reactivity, giving **3aj**, **3ak** and **3an** in 83-87% yield. Moreover, when the phenyl group was changed to 1-naphthalenylgroups, the reaction proceeded smoothly to deliver **3al** in 77% yield with improved *E*/*Z* selectivity.

**Table 2.** Scope of cyclopropyl acetylene substrates **2**[a],[b]

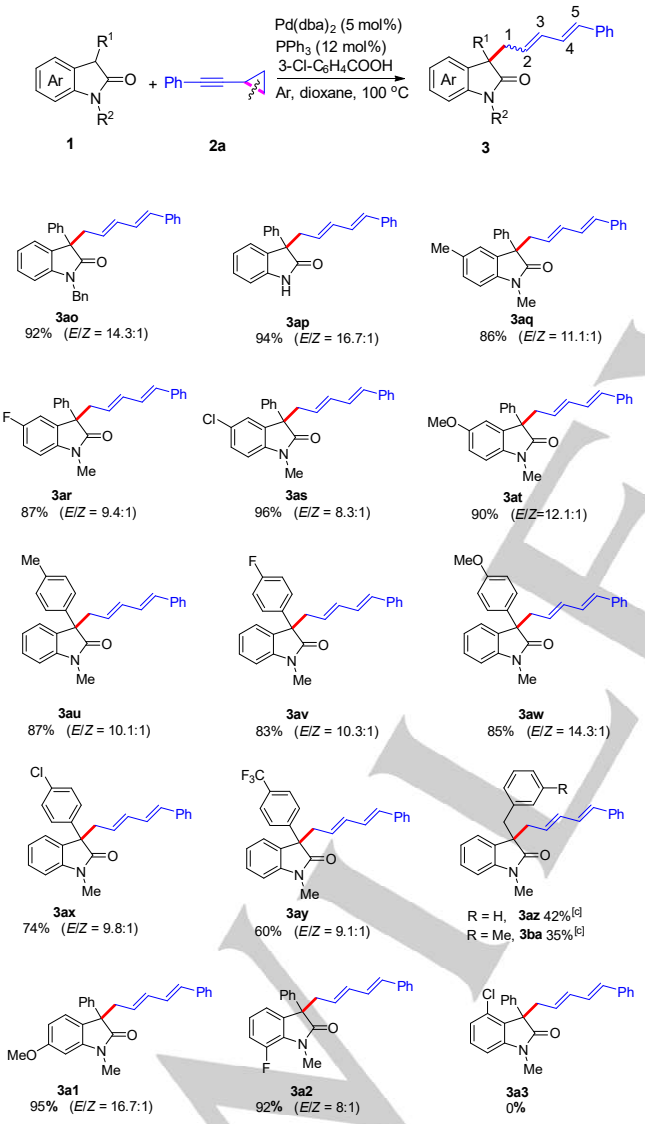



[a] Reaction conditions: **1a** (0.2 mmol), **2** (0.24 mmol), 3-Cl-$C_6H_4CO_2H$ (10 mol %), 5 mol% $Pd(dba)_2$ catalyst, 12 mol% $PPh_3$ in 2.0 mL dioxane at 100 °C for 12 h. [b] Isolated yields and the yields are reported as a mixture of *E* and *Z* isomers at 2-position.

Next, we turned our attention to explore the generality of the oxindoles under the standard conditions and the results are summarized in Table 3. Initially, *N*-substitution of the oxindole nitrogen was investigated (Table 3, **3ao**-**3ap**). Other than the methyl group, benzyl substituent was also well accommodated. Interestingly, non-protected free NH on the oxindole ring was also tolerated (**3ap**), which allows for facile potential *N*-substitutions on demand. The substituted group on the phenyl ring of oxindole (R) was then examined (Table 3). Differently substituted reacted well to produce **3** in high yields with excellent regio-, and stereoselectivities. It was found that oxindoles possessing electron-rich groups gave better *E*/*Z* stereoselectivities than that possessing electron-deficient groups on the phenyl ring (Table 3, **3aq**-**3at**). Substitution at the C3-position of the oxindole frame was then evaluated. It was found that the 3-phenyl ring bearing both electron-withdrawing halogen atoms and electron-donating methyl and methoxy substituents were well accommodated,

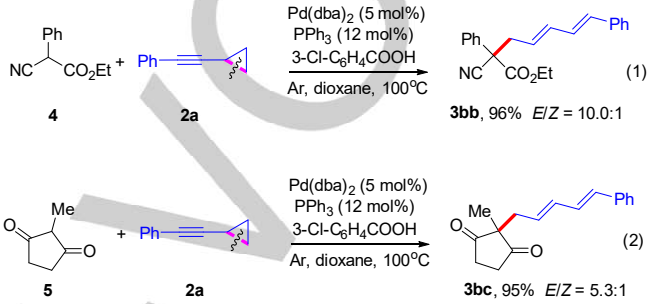
affording the desired 1,3-dienes products at good yields and stereoselectivities. Moreover, for oxindole with an alkyl substituent at the C3-position, the allylic alkylation proceeded regioselectively at the terminal position to produce **3az** and **3ba** in moderate yields. The final investigation of the reaction was focused on varying the substituents on the phenyl ring of 2-oxindoles. The outcome of the reaction depends much on the nature of the substituents. For example, oxindole substrates with methoxy at the C-6 position and fluoro at the C-7 position led to corresponding products **3a1** and **3a2** in 95% and 92% yields, respectively. However, when 4-Cl substituted oxindole was used, no desired product **3a3** could be detected probably due to the steric hindrance at the C-4 position.

**Table 3.** Scope of oxindole substrates **1** [a],[b]



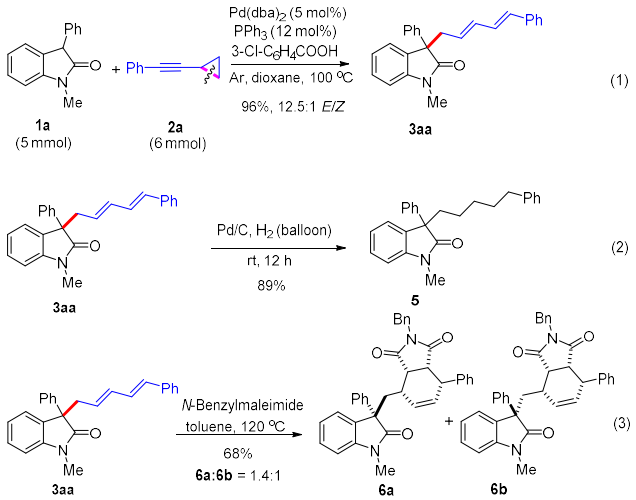

[a] Reaction conditions: **1** (0.2 mmol), **2a** (0.24 mmol), 3-Cl-$C_6H_4CO_2H$ (10 mol %), 5 mol% $Pd(dba)_2$ catalyst, 12 mol% ligand in 2.0 mL dioxane at 100 °C for 12 h. [b] Isolated yields and the yields are reported as a mixture of *E* and *Z* isomers at 2-position. [c] Only one isomer was detected.

Besides the oxindole, we also tried two other ketone and ester carbon nucleophiles (Scheme 2). Under the optimized conditions, These two kind of nucleophiles **4** and **5** exhibited marvellous reactivities to react with cyclopropyl phenyl acetylene **2a**. The desired products **3bb** and **3bc** could be obtained in 96% and 95% yields with good stereoselectivities.




**Scheme 2.** Scope of other carbon nucleophiles.

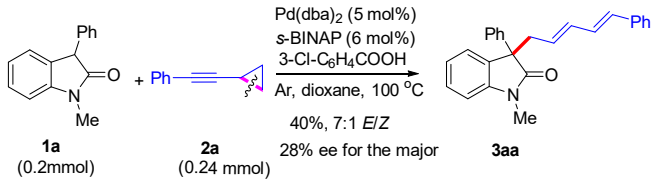
To test the practicability of the present method, a scaled-up reaction was conducted (Scheme 3, (1)). In the presence of 5 mol % of $Pd(dba)_2$ and 10 mol% of 3-chlorobenzoic acid as additive in anhydrous 1,4-dioxane at 100 °C under argon for 12 h, **3aa** could also be isolated in 96% yield on a 5.0 mmol scale. Subsequently, synthetic transformations of the product were conducted. As shown in Scheme 2, Pd/C-catalyzed hydrogenation of **3aa** in ethanol readily afforded oxindole **5** in 89% yield (Scheme 3, (2)). A Diels-Alder reaction of **3aa** with N-benzylmaleimide produced polycyclic compounds **6a** and **6b** in 68% combined yield (Scheme 3, (3)).




**Scheme 3.** Scaled-up reaction and synthetic transformations of **3aa**

Moreover, preliminary result shown in Scheme 4 indicated that this reaction was amendable to enantioselective catalysis

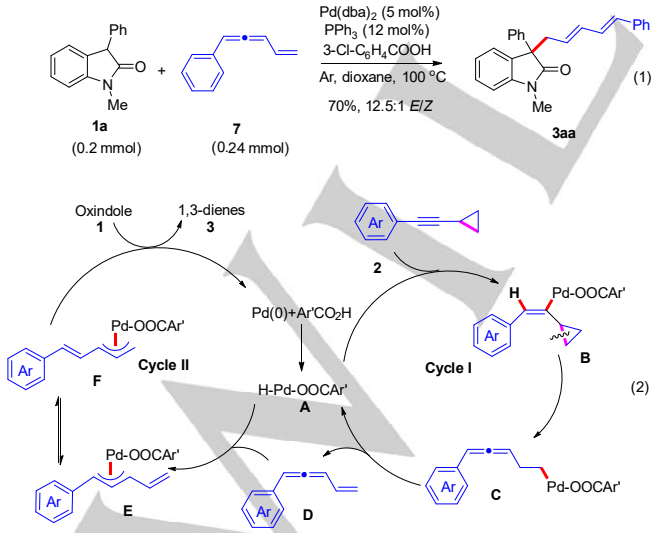
albeit the ee value was unsatisfied at this stage. Under the catalysis of a chiral Palladium/(*S*)-BINAP complex, the reaction of methyl-3-phenyloxindole **1a** and cyclopropyl phenyl acetylene **2a** proceeded smoothly to afford the oxindole framework **3aa** in 40% yield (12.5:1 *E*/*Z* selectivity) and with 28% ee for the major product. (Scheme 4)




**Scheme 4.** Preliminary result for the enantioselective reaction

In order to explore the mechanism of this reaction, we synthesized penta-1,2,4-trien-1-ylbenzene **7** and used it to react with oxindole **1a** (Scheme 5, (1)). Under the optimized reaction conditions, the reaction proceeded smoothly to afford allylation product **3aa** in 70% yield and 12.5:1 *E*/*Z* selectivity, suggesting that the alkyne **2** is capable of undergoing C-C activation to allene through a *β*-C-elimination.

The reasonable mechanism for the direct allylic alkylation of the oxindoles can be envisioned (Scheme 5, (2)). The palladium (0) complex is able to undergo oxidative addition to acid to generate a hydridopalladium complex, which then reacts with alkynes forming vinyl palladium intermediate **B**. The resulting vinylpalladium species would produce active alkylpalladium(II) intermediate **C** via β-C elimination. β-Hydrogen elimination of alkylpalladium(II) species **C** produces the vinyl allene **D**. Next, hydropalladation of vinyl allene intermediate **D** delivers the π-allylpalladium species **E** (Cycle II), which delivers intermediate **F** through π−σ−π isomerization. Finally, the palladium-allyl species **F** is captured by the oxindole nucleophile **1** to afford the desired product **3** and regenerated intermediate **A** to achieve the catalytic cycle.




**Scheme 5.** Control reaction and proposed mechanism for the tandem allylic alkylation reaction

## Conclusions

In conclusion, we have developed a palladium-catalyzed allylic alkylation of oxindoles with cyclopropyl acetylene for the synthesis of 1,3-diene oxindole framework bearing a quaternary stereocenter at the C3 position with high regio-, and stereoselectivities under mild conditions. This methodology was found to be advantageous in terms of substrate scope and functional group tolerance and shows excellent atom economy.

## Experimental Section

### Materials and methods

Reactions and manipulations involving organometallic or moisture sensitive compounds were performed under dry nitrogen and using glassware heated in an oven for 2 h prior to use. $^{1}H$ and $^{13}C$ spectra were recorded on a Bruker AVANCE III 500 MHz instrument using $CDCl_3$ as the solvent with TMS as the internal standard. Anhydrous dioxane, THF, and toluene were freshly distilled over Na and stored under nitrogen. Commercial reagents were used as received without further purification unless otherwise noted. Melting points (m.p.) were recorded using an SGW Melting Point X-4 instrument. IR was recorded using a Thermo Nicolet 6700 instrument. HRMS were recorded using an Agilent 6210 TOF LC/MS mass spectrometer. Column chromatography was carried out using a silica gel (200-300 mesh).

**General procedure for the synthesis of alkynes[16]**

CuI (77 mg, 0.4 mmol, 4.0 mol%), $(PPh_3)_2PdCl_2$ (141 mg, 0.2 mmol, 2.0 mol%), $PPh_3$ (105 mg, 0.4 mmol, 4.0 mol%), and $NEt_3$ (30 mL) were placed in a round-bottomed flask equipped with a magnetic stirring bar. After addition of the aryl halide (10.0 mmol), the mixture was stirred at 25 °C for 30 min, and cyclopropylacetylene (661 mg, 10.0 mmol) was then added. The reaction mixture was stirred at the same temperature for 16 h, saturated $NH_4Cl$ solution was added. The mixture was extracted with ethyl acetate and the combined organic layers were dried with $MgSO_4$ and concentrated under vacuum. The residue was purified by flash chromatography ($SiO_2$) to get the alkyne products.

**General procedure for the synthesis of substituted oxindoles[17]**

Substituted isatins (10.0 mmol) were dissolved in anhydrous DMF (15 mL), and the resultant solution was cooled to 0 ºC. Sodium hydride (60% dispersion in oil, 0.95 g, 12.0 mmol) was added in one portion and stirred for 5 min. Alkyl halide (15.0 mmol) was added and the reaction was stirred at 0 ºC for 30 min. The reaction mixture was then poured into saturated aqueous $NH_4Cl$ and extracted with ethyl acetate. The combined organic layers were washed with water and brine, dried over $Na_2SO_4$, filtered, and concentrated to give the crude N-substituted isatins.

The crude *N*-substituted isatins (10.0 mmol) were dissolved in anhydrous THF (15 mL) and cooled to 0 ºC, followed by dropwise addition of a 2.0 M of Grignard reagent in THF (12.0 mL, 24.0 mmol). Then the reaction was stirred under argon atmosphere at room temperature for 30 min with the consumption of the starting material. The reaction mixture was poured into saturated aqueous $NH_4Cl$, and extracted with ethyl acetate. The combined organic layers were washed with brine, dried over anhydrous $Na_2SO_4$, filtered, and concentrated to give the crude alcohol.

The crude alcohol (1.2 g, 5.0 mmol) was dissolved in 30 ml of glacial acetic acid and $SnCl_2$•2 $H_2O$ (10.0 mmol) was added. The reaction mixture was

stirred at 80 °C for 4 h at which point TLC analysis indicated consumption of the starting material. Then the reaction solution was cooled to room temperature, concentrated in vacuo, and diluted with ethyl acetate. The solution was then washed with water and brine. The organic layer was dried with anhydrous $Na_2SO_4$, filtered, and concentrated in vacuo. The residue was purified by flash column chromatography with EA/PE to afford the oxindole products.

**General procedure for the synthesis of 3-benzyl-1-methylindolin-2-one[17]**

Benzaldehyde (1.7 mL, 17 mmol) and piperidine (0.3 mL, 30 mmol) were added to a suspension of oxindole (2.0 g, 15 mmol) in ethanol (2 mL). The resulting mixture was heated to 150 °C. The solution was then allowed to cool to 0 °C. The precipitate was filtered, washed with small amount of ether, and dried to give 3-benzylidene-oxindole as a yellow solid, which was used without further purification.

The crude benzylidene oxindole was dissolved in DMF (30 mL) and cooled to 0 °C. NaH (720 mg, 18 mmol, 60% in mineral oil) was added and the resulting solution was stirred for 15 min before methyl iodide (2.9 g, 20mmol) was added dropwise. The reaction was allowed to warm to room temperature and stirred for another 2 h. Water was then added to quench the reaction. The mixture was extracted with EtOAc and the combined organic layer was washed with water and brine, and dried over $MgSO_4$, and concentrated to about 10 mL in volumn. The solution was filtered through a pad of silica to afford the oxindole.

The crude oxindole was dissolved in EtOAc and Pd/C (10%) was added. The suspension was stirred in the presence of a $H_2$ balloon for 10 h. The reaction was then filtered through a pad of wet celite and the filtrate was concentrated to give a slightly yellow oil. After purification by flash column chromatography of the crude oil, 3-benzyl-1-methylindolin-2-one was achieved as a white solid.

**General procedure for the palladium-catalyzed allylation of oxindole with cyclopropyl acetylene derivatives**

To a mixture of oxindole **1** (0.20 mmol, 1.0 equiv), cyclopropyl acetylene derivatives **2** (0.24 mmol, 1.2 equiv), $Pd(dba)_2$ (0.01 mmol, 5 mol%), $PPh_3$ (0.024 mmol, 12 mol%) and *m*-chlorobenzoic acid (0.02 mmol, 10 mol%) in a sealed tube (10 mL) was added 2.0 mL dry dioxane. The resulting mixture was then stirred at 100 °C under argon atmosphere for 12 h. The solvent was then removed under vacuum and the residue was purified with chromatography on silica (PE/EA = 20:1) to afford a mixture of stereoisomers of compound **3** and the *E*/*Z* ratio was determined by $^1$H NMR. The mixture of stereoisomers was separated by a second chromatography on silica (PE/EA = 30:1) to afford the major stereoisomer.

**1-Methyl-3-phenyl-3-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)indolin-2-one (3aa)**. Total isolated yield: 98%, 2*E*/2*Z* = 12.5:1. Purified **3aa**, pale yellow solid, m. p. 108–110 °C . $^1$H NMR (500 MHz, $CDCl_3$) δ 7.45-7.41 (m, 2H), 7.38-7.32 (m, 5H), 7.31-7.27 (m, 4H), 7.23-7.18 (m, 1H), 7.15 (td, *J* = 7.6, 1.0 Hz, 1H), 6.92 (d, *J* = 7.8 Hz, 1H), 6.56 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.41 (d, *J* = 15.5 Hz, 1H), 6.21 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.45-5.38 (m, 1H), 3.22 (s, 3H), 3.21-3.19 (m, 1H), 3.08 (dd, *J* = 14.0, 8.5 Hz, 1H). HRMS (ESI) m/z calculated for $[C_{26}H_{23}NO+H]^+$ 366.1852, found 366.1858.

**3-((2E,4E)-5-(3-Methoxyphenyl)penta-2,4-dien-1-yl)-1-methyl-3-phenylindolin-2-one (3ab)**. Total isolated yield: 69%, 2*E*/2*Z* = 12.0:1. Purified **3ab**, yellow solid, m. p. 100–102 °C. 1H NMR (500 MHz,$CDCl_3$) δ 7.47-7.42 (m, 2H), 7.38-7.33 (m,3H), 7.32-7.26 (m,4H), 7.15 (td, *J* = 7.5, 1.0 Hz, 1H), 6.92 (d, *J* = 8.0 Hz, 1H), 6.86- 6.82 (m, 2H), 6.45 (dd, *J* = 15.0, 10.0 Hz, 1H), 6.37 (d, *J* = 15.5 Hz, 1H), 6.20 (dd, *J* = 15.0, 10.0 Hz, 1H), 5.41-5.35 (m, 1H), 3.80 (s, 3H), 3.23-3.17 (m, 1H), 3.22(s, 3H), 3.10-3.06 (m, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.98, 159.13, 143.84, 139.44, 134.84, 131.72, 131.06, 130.12, 128.56, 128.26, 127.42, 127.36, 127.14, 126.94, 126.62, 125.25, 122.48, 114.05, 108.28, 56.73, 55.28, 41.20, 26.40. HRMS (ESI) m/z calculated for $[C_{27}H_{25}NO_2+H]^+$ 396.1958, found 396.1961.

**1-Methyl-3-phenyl-3-((2E,4E)-5-(m-tolyl)penta-2,4-dien-1-yl)indolin-2-one (3ac)**. Total isolated yield: 80%, 2*E*/2*Z* = 10.3:1. Purified **3ac**, yellow oil. 1H NMR (500 MHz, $CDCl_3$) δ 7.45-7.42 (m, 2H), 7.38-7.33 (m, 3H), 7.32-7.28 (m, 2H), 7.19-7.11 (m, 4H), 7.03 (d, *J* = 7.0 Hz, 1H), 6.92 (d, *J* = 7.5 Hz, 1H), 6.56 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.38 (d, *J* = 16.0 Hz, 1H), 6.21 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.44-5.38 (m, 1H), 3.22 (s, 3H), 3.21-3.16 (m, 1H), 3.08 (dd, *J* = 13.5, 8.5 Hz, 1H), 2.33 (s, 3H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.92, 143.81, 139.35, 138.04, 137.18, 134.70, 131.62, 131.59, 128.55, 128.42, 128.38, 128.26, 128.18, 127.98, 127.36, 127.10, 126.85, 125.23, 123.42, 122.47, 108.27, 56.67, 41.15, 26.40, 21.35. HRMS (ESI) m/z calculated for $[C_{27}H_{25}NO+H]^+$ 380.2009, found 380.2012.

**3-((2E,4E)-5-(3-Fluorophenyl)penta-2,4-dien-1-yl)-1-methyl-3-phenylindolin-2-one (3ad)**. Total isolated yield: 95%, 2*E*/2*Z* = 12.2:1. Purified **3ad**, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.46-7.42 (m, 2H), 7.39-7.33 (m, 3H), 7.32-7.28 (m, 2H), 7.24 (td, *J* = 8.0, 6.0 Hz, 1H), 7.16 (td, *J* = 7.5, 1.0 Hz, 1H), 7.092-7.071 (m, 1H), 7.03 (dt, *J* = 10.5, 2.0 Hz, 1H), 6.94-6.87 (m, 2H), 6.55 (dd, *J* = 16.0, 10.5 Hz, 1H), 6.37 (d, *J* = 15.5 Hz, 1H), 6.21 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.49-5.43 (m, 1H), 3.23 (s, 3H), 3.22-3.17 (m, 1H), 3.13-3.07 (m, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.85, 163.08 (d, $^1J$ = 245.1 Hz), 143.80, 139.67 (d, $^3J$ = 7.6 Hz), 139.31, 134.19, 131.56, 130.22(d, $^4J$ = 2.8 Hz), 129.91(d, $^3J$ = 8.5 Hz), 129.82, 129.39, 128.57, 128.32, 127.39, 127.07, 125.18, 122.50, 122.15(d, $^4J$ = 2.8 Hz), 114.07(d, $^2J$ = 21.4 Hz), 112.43(d, $^2J$ = 21.8 Hz), 108.30, 56.60, 41.14, 26.39. HRMS (ESI) m/z calculated for $[C_{26}H_{22}FNO+Na]^+$ 406.1567, found 406.1571.

**3-((2E,4E)-5-(3-Chlorophenyl)penta-2,4-dien-1-yl)-1-methyl-3-phenylindolin-2-one (3ae)**. Total isolated yield: 89%, 2*E*/2*Z* = 12.5:1. Purified **3ae**, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.44-7.41 (m, 2H), 7.38-7.28 (m, 6H), 7.21-7.13 (m, 4H), 6.92 (d, *J* = 8.0 Hz, 1H), 6.54 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.33 (d, *J* = 16.0 Hz, 1H), 6.19 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.48-5.42 (m, 1H), 3.22 (s, 3H), 3.20-3.16 (m, 1H), 3.11-3.07 (m, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.87, 143.81, 139.30, 139.20, 134.51, 134.19, 131.57, 129.94, 129.72, 129.51, 128.58, 128.34, 127.41, 127.20, 127.08, 125.94, 125.19, 124.48, 122.53, 108.32, 56.62, 41.14, 26.42. HRMS (ESI) m/z calculated for $[C_{26}H_{22}ClNO+Na]^+$ 422.1284, found 422.1286.

**1-Methyl-3-phenyl-3-((2E,4E)-5-(p-tolyl)penta-2,4-dien-1-yl)indolin-2-one (3af)**. Total isolated yield: 77%, 2*E*/2*Z* = 9.7:1. Purified 3af, Purified **3af**, yellow solid, m. p. 84–86 °C; $^1$H NMR (500 MHz, $CDCl_3$) δ 7.46-7.42 (m, 2H), 7.38-7.33 (m, 3H), 7.31-7.28 (m, 2H), 7.23 (d, *J* = 8.0 Hz, 2H), 7.15 (td, *J* = 7.5, 1.0 Hz, 1H), 7.10 (d, *J* = 8.0 Hz, 2H), 6.92 (d, *J* = 7.5 Hz, 1H), 6.52 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.39 (d, *J* = 15.5 Hz, 1H), 6.20 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.42-5.37 (m, 1H), 3.24-3.17( m, 1H), 3.22 (s, 3H), 3.11-3.07 (m, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.93, 143.83, 139.40, 137.21, 134.77, 134.50, 131.67, 131.45, 129.25, 128.54, 128.25, 127.64, 127.55, 127.35, 127.12, 126.12, 125.24, 122.46, 108.26, 56.69, 41.18, 26.39, 21.18. HRMS (ESI) m/z calculated for $[C_{27}H_{25}NO+H]^+$ 380.2009, found 380.2014.

**3-((2E,4E)-5-(4-Fluorophenyl)penta-2,4-dien-1-yl)-1-methyl-3-phenylindolin-2-one (3ag)**. Total isolated yield: 85%, 2*E*/2*Z* = 10.0:1. Purified **3ag**, yellow solid, m. p. 94–96 °C. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.45-7.41 (m, 2H), 7.41-7.38 (m, 1H), 7.38-7.32 (m, 3H), 7.31-7.28 (m, 2H), 7.19-7.12 (m, 2H), 7.08-6.98 (m, 2H), 6.92 (d, *J* = 8.0 Hz, 1H), 6.63 (dd, *J* = 16.0, 10.0 Hz, 1H), 6.55 (d, *J* = 15.5 Hz, 1H), 6.22 (dd, *J* = 15.0, 10.0 Hz, 1H), 5.50-5.43 (m, 1H), 3.22 (s, 3H), 3.22-3.17 (m, 1H), 3.11-3.06 (m, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.89, 160.19 (d, $^1J$ = 247.5 Hz), 143.80,

139.31, 134.82, 131.59, 130.89 (d, $^3J$ = 5.0 Hz), 129.15, 128.57, 128.45 (d, 2J = 8.8 Hz), 128.31, 127.39, 127.10, 126.94 (d, $^4J$ = 3.8 Hz), 125.23, 125.11 (d, $^2J$ = 11.8 Hz), 124.02 (d, $^5J$ = 3.8 Hz), 123.76 (d,$^6J$ =2.5 Hz), 122.52, 115.69 (d, $^2J$ = 22.5 Hz), 108.30, 56.60, 41.14, 26.42. HRMS (ESI) m/z calculated for $[C_{26}H_{22}FNO+H]^+$ 384.1758, found 384.1763.

**3-((2E,4E)-5-(4-Chlorophenyl)penta-2,4-dien-1-yl)-1-methyl-3-phenylindolin-2-one (3ah)**. Total isolated yield: 88%, 2*E*/2*Z* = 12.5:1. Purified **3ah**, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.43-7.40 (m, 2H), 7.38-7.31 (m, 3H), 7.30-7.28 (m, 2H), 7.24 (s, 4H), 7.15 (td, *J* = 7.5, 1.0 Hz, 1H), 6.92 (d, *J* = 8.0 Hz, 1H), 6.52 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.34 (d, *J* = 15.5 Hz, 1H), 6.19 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.46-5.39 (m, 1H), 3.22 (s, 3H), 3.20-3.15 (m, 1H), 3.11-3.05 (m, 1H). $^{13}$C NMR (125 MHz, CDCl3) δ 177.88, 143.80, 139.30, 135.79, 134.33, 132.86, 131.59, 130.12, 129.15, 128.94, 128.68, 128.58, 128.32, 127.40, 127.35, 127.09, 125.20, 122.51, 108.31, 56.61, 41.14, 26.42. HRMS (ESI) m/z calculated for $[C_{26}H_{22}ClNO+Na]^+$ 422.1286, found 422.1288.

**1-Methyl-3-phenyl-3-((2E,4E)-5-(4-(trifluoromethyl)phenyl)penta-2,4-dien-1-yl)indolin-2-one (3ai)**. Total isolated yield: 97%, 2*E*/2*Z* = 12.7:1. Purified **3ai**, solid, m. p. 98–100 °C; $^1$H NMR (500 MHz, $CDCl_3$) δ 7.54 (d, *J* = 8.2 Hz, 2H), 7.47-7.43 (m, 2H), 7.42-7.39 (m, 2H), 7.39-7.33 (m, 3H), 7.33-7.29 (m, 2H), 7.17 (td, *J* = 7.5, 1.0 Hz, 1H), 6.94 (d, *J* = 7.5 Hz, 1H), 6.64 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.42 (d, *J* = 15.5 Hz, 1H), 6.24 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.55-5.49 (m, 1H), 3.23 (s, 3H), 3.22-3.18 (m, 1H), 3.15-3.09 (m, 1H). $^{13}$C NMR (125 MHz, CDCl3) δ 177.82, 143.80, 140.77, 139.27, 134.12, 131.54, 130.95, 130.25, 129.87, 128.96(q,$^2J$ = 32.3),128.59, 128.36, 127.43, 127.06, 126.25, 125.44 (q, $^3J$ = 3.9 Hz), 125.16,124.20(q, $^1J$ = 268.8), 122.52, 108.33, 56.57, 41.13, 26.38. HRMS (ESI) m/z calculated for $[C_{27}H_{22}F_3NO+Na]^+$ 456.1543, found 456.1541.

**1-Methyl-3-phenyl-3-((2E,4E)-5-(o-tolyl)penta-2,4-dien-1-yl)indolin -2-one (3aj)**. Total isolated yield: 83%, 2*E*/2*Z* = 10.0:1. Purified **3aj**, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.46-7.42 (m, 2H), 7.39-7.33 (m, 3H), 7.32-7.28 (m, 2H), 7.21-7.12 (m, 4H), 7.03 (d, *J* = 7.0 Hz, 1H), 6.92 (d, *J* = 7.5 Hz, 1H), 6.56 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.39 (d, *J* = 15.5 Hz, 1H), 6.21 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.45-5.39 (m, 1H), 3.22 (s, 3H), 3.22-3.17 (m, 1H), 3.11-3.07 (m, 1H), 2.34 (s, 3H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.96, 143.87, 139.41, 138.07, 137.24, 134.75, 131.68, 131.64, 128.59, 128.47, 128.43, 128.31, 128.23, 128.02, 127.40, 127.15, 126.90, 125.27, 123.48, 122.51, 108.31, 56.72, 41.21, 26.43, 21.39. HRMS (ESI) m/z calculated for $[C_{27}H_{25}NO+H]^+$ 380.2009, found 380.2016.

**3-((2E,4E)-5-(2-Fluorophenyl)penta-2,4-dien-1-yl)-1-methyl-3-phenylindolin-2-one (3ak).** Total isolated yield: 85%, 2*E*/2*Z* = 11.5:1. Purified **3ak**, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.46-7.42 (m, 2H), 7.41-7.33 (m, 4H), 7.32-7.28 (m, 2H), 7.19-7.14 (m, 2H), 7.08-6.99 (m, 2H), 6.92 (d, *J* = 8.0 Hz, 1H), 6.64 (dd, *J* = 16.0, 10.0 Hz, 1H), 6.55 (d, *J* = 16.0 Hz, 1H), 6.23 (dd, *J* = 15.0, 10.0 Hz, 1H), 5.50-5.44 (m, 1H), 3.23 (s, 3H), 3.22-3.18 (m, 1H), 3.12-3.07 (m, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.87, 160.18 (d, $^1J$ = 249.7 Hz), 143.79, 139.31, 134.82, 131.58, 130.89 (d, $^3J$ = 5.2 Hz), 129.15, 128.56, 128.45 (d, $^3J$ = 8.3 Hz), 128.30, 127.38, 127.10, 126.94 (d, $^3J$ = 3.6 Hz), 125.22, 125.10 (d, $^2J$ = 12.1 Hz), 124.00 (d, $^4J$ = 3.5 Hz), 123.75 (d, $^4J$ = 3.2 Hz), 122.51, 115.68 (d, $^2J$ = 22.2 Hz), 108.29, 56.59, 41.14, 26.40. HRMS (ESI) m/z calculated for $[C_{26}H_{22}FNO+Na]^+$ 406.1573, found 406.1570.

**1-Methyl-3-((2E,4E)-5-(naphthalen-2-yl)penta-2,4-dien-1-yl)-3-phenylindolin-2-one (3al)**. Total isolated yield: 77%, 2*E*/2*Z* = 16.0:1. Purified **3al**, yellow oil. 1H NMR (500 MHz, $CDCl_3$) δ 8.14-8.10 (m, 1H), 7.85 (dd, *J* = 8.0, 1.5 Hz, 1H), 7.75 (d, *J* = 8.0 Hz, 1H), 7.58 (d, *J* = 7.0 Hz, 1H), 7.55-7.49 (m, 2H), 7.49-7.44 (m, 2H), 7.44-7.40 (m, 1H), 7.39-7.29 (m, 5H), 7.22-7.15 (m, 2H), 6.93 (d, *J* = 8.0 Hz, 1H), 6.64 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.38 (dd, *J* = 15.5, 10.5 Hz, 1H), 5.51-5.45 (m, 1H), 3.24 (s, 3H), 3.23-3.21 (m, 1H), 3.18-3.12 (m, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.93, 143.83, 139.37, 134.88, 134.54, 133.71, 131.64, 131.31, 131.06, 128.58, 128.56, 128.53, 128.30, 128.11, 127.77, 127.39, 127.11, 125.97, 125.71, 125.50, 125.21, 123.53, 123.01, 122.52, 108.29, 56.68, 41.18, 26.41. HRMS (ESI) m/z calculated for $[C_{30}H_{25}NO+Na]^+$ 438.1824, found 438.1821.

**3-((2E,4E)-5-(3,5-Dimethylphenyl)penta-2,4-dien-1-yl)-1-methyl-3-phenylindolin-2-one (3am)**. Total isolated yield: 71%, 2*E*/2*Z* = 7.6:1. Purified **3am**, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.46-7.42 (m, 2H), 7.38-7.32 (m, 3H), 7.3-7.28 (m, 2H), 7.15 (td, *J* = 7.5, 1.0 Hz, 1H), 6.97 (s, 2H), 6.92 (d, J = 8.0 Hz, 1H), 6.86 (s, 1H), 6.57-6.52 (dd, *J*=15.5,10.5 Hz ,1H), 6.35 (d, *J* = 16 Hz, 1H), 6.20 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.43-5.37 (m , 1H), 3.25-3.17 (m, 1H), 3.40 (s, 3H), 3.11-3.06 (m, 1H), 2.30 (s, 6H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.94, 143.86, 139.41, 137.95, 137.19, 134.79, 131.71, 131.68, 129.17, 128.55, 128.26, 128.26, 127.78, 127.35, 127.12, 125.25, 124.13, 122.46, 108.25, 56.71, 41.19, 29.71, 26.39, 21.21. HRMS (ESI) m/z calculated for $[C_{28}H_{27}NO+Na]^+$ 416.1985, found 416.1985.

**3-((2E,4E)-5-(2-Fluoro-4-methylphenyl)penta-2,4-dien-1-yl)-1-methyl-3-phenylindolin-2-one (3an)**. Total isolated yield: 87%, 2*E*/2*Z* = 11.6:1. Purified **3an**, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.45-7.41 (m, 2H), 7.38-7.32 (m, 3H), 7.31-7.28 (m, 2H), 7.27-7.24 (m, 1H), 7.15 (td, *J* = 7.5, 1.0 Hz, 1H), 6.92 (d, *J* = 8.0 Hz, 1H), 6.85 (dd, J = 15.5, 8.0 Hz, 2H), 6.59 (dd, *J* = 16.0, 10.0 Hz, 1H), 6.51 (d, *J* = 15.5 Hz, 1H), 6.21 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.47-5.40 (m, 1H), 3.22 (s, 3H),3.22-3.16 (m, 1H), 3.10-3.05 (m, 1H), 2.32 (s, 3H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.91, 160.07 (d, $^1J$ = 249.6 Hz), 143.81, 139.36, 139.14 (d, $^3J$ = 8.1 Hz), 134.97, 131.63, 129.91 (d, $^3J$ = 5.2 Hz), 128.57, 128.48, 128.29, 127.37, 127.12, 126.69 (d, $^3J$ = 4.3 Hz), 125.25, 124.83 (d, $^4J$ = 2.9 Hz), 123.88 (d, $^4J$ = 3.0 Hz), 122.50, 122.17 (d, $^2J$ = 12.4 Hz), 116.21 (d, $^2J$ = 22.0 Hz), 108.29, 56.62, 41.17, 26.41, 21.07. HRMS (ESI) m/z calculated for $[C_{27}H_{24}FNO+Na]^+$ 420.1730, found 420.1728.

**1-Benzyl-3-phenyl-3-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)indolin-2-one (3ao)**. Total isolated yield: 92%, 2*E*/2*Z* = 14.3:1. Purified **3ao**, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.48 (d, *J* = 7.5 Hz, 2H), 7.40-7.35 (m, 4H), 7.35-7.29 (m, 5H), 7.27-7.21 (m, 4H), 7.20-7.16 (m, 1H), 7.13 (t, *J* = 7.5 Hz, 1H), 6.79 (d, *J* = 7.5 Hz, 1H), 6.56 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.46 (d, *J* = 15.5 Hz, 1H), 6.33 (dd, *J* = 15.0, 10.0 Hz, 1H), 5.43-5.37 (m, 1H), 5.15 (d, *J* = 16.0 Hz, 1H), 4.73 (d, *J* = 16.0 Hz, 1H), 3.33-3.26 (m, 1H), 3.24-3.20 (m, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.97, 142.98, 139.74, 137.25, 135.74, 134.89, 131.72, 131.70, 128.71, 128.62, 128.57, 128.55, 128.27, 128.20, 127.45, 127.43, 127.39, 127.36, 127.01, 126.23, 125.03, 122.57, 109.41, 56.79, 43.97, 41.16. HRMS (ESI) m/z calculated for $[C_{32}H_{27}NO+Na]^+$ 464.1980, found 464.1976.

**3-Phenyl-3-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)indolin-2-one (3ap)**. Total isolated yield: 94%, 2*E*/2*Z* = 16.7:1. Purified **3ap**, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 8.91 (s, 1H), 7.44-7.41 (m, 2H), 7.36-7.32 (m, 2H), 7.30-7.27 (m, 6H), 7.25-7.23 (m, 1H), 7.22-7.18 (m, 1H), 7.11 (td, *J* = 7.5, 1.5 Hz, 1H), 6.98 (d, *J* = 8.0 Hz, 1H), 6.55 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.35 (d, *J* = 15.5 Hz, 1H), 6.22 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.50-5.44 (m, 1H), 3.21-3.17 (m, 1H), 3.13-3.09(m, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 180.50, 140.98, 139.22, 137.23, 134.79, 132.40, 131.55, 128.62, 128.54, 128.48, 128.23, 127.97, 127.42, 127.32, 127.06, 126.23, 125.38, 122.49, 110.19, 57.21, 40.81. HRMS (ESI) m/z calculated for $[C_{25}H_{21}NO+Na]^+$ 374.1512, found 374.1510.

**1,5-Dimethyl-3-phenyl-3-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)indolin-2-one (3aq).** Total isolated yield: 86%, 2*E*/2*Z* = 11.1:1. Purified **3aq**, yellow oil. 1H NMR (500 MHz, $CDCl_3$) δ 7.45-7.42 (m, 2H), 7.37-7.34 (m, 4H), 7.32-7.28 (m, 3H), 7.23-7.15 (m, 2H), 7.12 (d, *J* = 1.5 Hz, 1H),

6.81 (d, *J* = 8.0 Hz, 1H), 6.58 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.43 (d, *J* = 15.5 Hz, 1H), 6.25 (dd, *J* = 15.0, 10.5 Hz, 1H),5.46-5.39 (m, 1H), 3.21 (s, 3H), 3.20-3.16 (m, 1H),3.14-3.09 (m, 1H), 2.40 (s, 3H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.86, 141.44, 139.62, 137.29, 134.53, 131.96, 131.79, 131.37, 128.62, 128.52, 128.50, 128.32, 127.30, 127.28, 127.08, 126.18, 125.84, 107.95, 56.77, 40.96, 26.39, 21.25. HRMS (ESI) m/z calculated for $[C_{27}H_{25}NO+Na]^+$ 402.1824, found 402.1820.

**5-Fluoro-1-methyl-3-phenyl-3-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)indolin-2-one (3ar)**. Total isolated yield: 87%, 2*E*/2*Z* = 9.4:1. Purified **3ar**, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.42-7.39 (m, 2H), 7.37-7.33 (m, 4H), 7.32-7.28 (m, 3H), 7.23-7.19 (m, 1H), 7.09-7.03 (m, 2H), 6.83 (dd, *J* = 8.0, 4.0 Hz, 1H), 6.56 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.43 (d, *J* = 15.5 Hz, 1H), 6.22 (dd, *J* = 15.0, 10.0 Hz, 1H), 5.43-5.36 (m, 1H), 3.21 (s, 3H), 3.18-3.08 (m, 2H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.63, 159.15 (d, $^1J$ = 240.9 Hz), 139.75 (d, $^4J$ = 1.6 Hz), 138.77, 137.14, 134.96, 133.34 (d, $^3J$ = 8.1 Hz), 131.80, 128.69, 128.54, 128.33, 127.60, 127.49, 127.43, 126.92, 126.23, 114.57 (d, $^2J$ = 23.6 Hz), 113.17 (d, $^2J$ = 24.8 Hz), 108.71 (d, $^3J$ = 8.1 Hz), 57.11, 40.95, 26.54. HRMS (ESI) m/z calculated for $[C_{26}H_{22}FNO+H]^+$ 384.1758, found 384.1765.

**5-Chloro-1-methyl-3-phenyl-3-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)indolin-2-one (3as)**. Total isolated yield: 96%, 2*E*/2*Z* = 8.3:1. Purified **3as**, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.42-7.39 (m, 2H), 7.38-7.33 (m, 5H), 7.33-7.28 (m, 4H), 7.24-7.19 (m, 1H), 6.83 (d, *J* = 8.0 Hz, 1H), 6.57 (dd, *J* = 16.0, 10.0 Hz, 1H), 6.44 (d, *J* = 16.0 Hz, 1H), 6.24 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.39 (dt, *J* = 15.0, 7.5 Hz, 1H), 3.21 (s, 3H), 3.18-3.09 (m, 2H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.46, 142.40, 138.73, 137.17, 135.04, 133.51, 131.86, 128.71, 128.53, 128.32, 128.28, 127.92, 127.63, 127.43, 127.34, 126.91, 126.24, 125.42, 109.17, 57.00, 40.92, 26.48. HRMS (ESI) m/z calculated for $[C_{26}H_{22}ClNO+Na]^+$ 422.1277, found 422.1274.

**5-Methoxy-1-methyl-3-phenyl-3-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)indolin-2-one (3at).** Total isolated yield: 90%, 2*E*/2*Z* = 12.1:1. Purified **3at**, yellow solid, m. p. 101–103 °C. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.44-7.41 (m, 2H), 7.37-7.28 (m, 7H), 7.23-7.18 (m, 1H), 6.93-6.88 (m, 2H), 6.82 (d, *J* = 8.0 Hz, 1H), 6.58 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.42 (d, *J* = 15.5 Hz, 1H), 6.23 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.46-5.40 (m, 1H), 3.81 (s, 3H), 3.20 (s, 3H), 3.19-3.15 (m, 1H), 3.10-3.06 (m, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.58, 155.84, 139.29, 137.36, 137.23, 134.66, 132.97, 131.48, 128.56, 128.51, 128.16, 127.36, 127.33, 127.06, 126.18, 112.54, 108.51, 57.06, 55.79, 40.96, 26.47. HRMS (ESI) m/z calculated for $[C_{27}H_{25}NO_2+H]^+$ 396.1958, found 396.1963.

**1-Methyl-3-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)-3-(p-tolyl)indolin-2-one (3au).** Total isolated yield: 87%, 2*E*/2*Z* = 10.1:1. Purified **3au**, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.40-7.35 (m, 2H), 7.34-7.28 (m, 6H), 7.24-7.20 (m, 1H), 7.18-7.15 (m, 3H), 6.92 (d, *J* = 7.5 Hz, 1H), 6.58 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.42 (d, *J* = 16.0 Hz, 1H), 6.23 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.48-5.42 (m, 1H), 3.22 (s, 3H), 3.20-3.17 (m, 1H), 3.10-3.05(m, 1H), 2.35 (s, 3H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 178.02, 143.77, 137.22, 137.03, 136.31, 134.51, 131.75, 131.37, 129.24, 128.56, 128.49, 128.34, 128.17, 127.30, 126.94, 126.15, 125.13, 122.42, 108.20, 56.32, 41.04, 26.35, 20.94. HRMS (ESI) m/z calculated for $[C_{27}H_{25}NO+Na]^+$ 402.1824, found 402.1821.

**3-(4-Fluorophenyl)-1-methyl-3-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)indolin-2-one (3av).** Total isolated yield: 83%, 2*E*/2*Z* = 10.3:1. Purified **3av**, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.43-7.39 (m, 2H), 7.38-7.32 (m, 3H), 7.31-7.28 (m, 3H), 7.23-7.19 (m, 1H), 7.17 (td, *J* = 7.5, 1.0 Hz, 1H), 7.05-7.01 (m, 2H), 6.93 (d, *J* = 8.0 Hz, 1H), 6.57 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.42 (d, *J* = 15.5 Hz, 1H), 6.21 (dd, *J* = 15.0, 10.5 Hz, 1H),5.43-5.37 (m, 1H), 3.22 (s, 3H), 3.15 (dd, *J* = 14.0, 6.5 Hz, 1H), 3.04 (dd, *J* = 14.0, 8.5 Hz, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.74, 162.06 (d, $^1J$ = 246.7 Hz), 143.71, 137.15, 134.98 (d, $^4J$ = 3.4 Hz), 134.77, 131.64, 131.25, 128.85 (d, $^3J$ = 8.1 Hz), 128.51, 128.43, 128.40, 127.80, 127.38, 126.19, 125.16, 122.56, 115.31 (d, $^2J$ = 21.3 Hz), 108.41, 56.01, 41.43, 26.39. HRMS (ESI) m/z calculated for $[C_{26}H_{22}FNO+Na]^+$ 406.1573, found 406.1570.

**3-(4-Methoxyphenyl)-1-methyl-3-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)indolin-2-one (3aw).** Total isolated yield: 85%, 2*E*/2*Z* = 14.3:1. Purified **3aw**, yellow solid, m. p. 126–129 °C. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.39-7.32 (m, 5H), 7.29 (t, *J* = 7.3 Hz, 3H), 7.23-7.19 (m, 1H), 7.15 (t, *J* = 7.5 Hz, 1H), 6.92 (d, *J* = 8.0 Hz, 1H), 6.90-6.86 (m, 2H), 6.57 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.41 (d, *J* = 16.0 Hz, 1H), 6.21 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.46-5.40 (m, 1H), 3.80 (s, 3H), 3.21 (s, 3H), 3.16 (dd, *J* = 14.0, 6.0 Hz, 1H), 3.04 (dd, *J* = 13.5, 9.0 Hz, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 178.14, 158.79, 143.74, 137.21, 134.50, 131.71, 131.38, 131.29, 128.55, 128.49, 128.34, 128.20, 127.30, 126.15, 125.15, 122.41, 113.88, 108.23, 55.93, 55.21, 41.22, 26.34. HRMS (ESI) m/z calculated for $[C_{27}H_{25}NO_2+Na]^+$ 418.1772, found 418.1769.

**3-(4-Chlorophenyl)-1-methyl-3-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)indolin-2-one (3ax).** Total isolated yield: 74%, 2*E*/2*Z* = 9.8:1. Purified **3ax**, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.40-7.36 (m, 3H), 7.35-7.28 (m, 7H), 7.23-7.19 (m, 1H), 7.16 (td, *J* = 7.5, 1.0 Hz, 1H), 6.93 (d, *J* = 8.0, 1H), 6.56 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.41 (d, *J* = 15.5 Hz, 1H), 6.20 (dd, *J* = 15.0, 10.0 Hz, 1H), 5.42-5.36 (m, 1H), 3.22 (s, 3H), 3.14 (dd, *J* = 14.5, 6.5 Hz, 1H), 3.02 (dd, *J* = 14.0, 8.5 Hz, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.50, 143.73, 137.77, 137.15, 134.87, 133.40, 131.72, 131.02, 128.64, 128.61, 128.53, 128.37, 127.66, 127.42, 126.21, 125.18, 122.62, 108.46, 56.14, 41.28, 26.45. HRMS (ESI) m/z calculated for $[C_{26}H_{22}ClNO+Na]^+$ 422.1282, found 422.1300.

**1-Methyl-3-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)-3-(4-(trifluoromethyl)phenyl)indolin-2-one (3ay)**. Total isolated yield: 60 %, 2E/2Z= 9.1:1. Purified **3ay**, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.58 (q, *J* = 8.5 Hz, 4H), 7.40 (td, *J* = 7.5, 1.5 Hz, 1H), 7.35-7.28 (m, 5H), 7.23-7.16 (m, 2H), 6.94 (d, *J* = 8.0 Hz, 1H), 6.56 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.42 (d, *J* = 15.5 Hz, 1H), 6.21 (dd, *J* = 15.0, 10.5 Hz, 1H),5.42-5.36 (m, 1H), 3.23 (s, 3H),3.21-3.16 (m, 1H),3.10-3.05 (m, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.18, 143.77, 143.31, 137.13, 135.08, 131.90, 130.76, 129.64(q, $^2J$ = 32.5), 128.71, 128.56, 128.30, 127.65, 127.48, 127.32, 126.25, 125.47 (q, $^3J$ = 3.9 Hz), 125.22, 124.07(q, $^1J$ = 270.0), 122.75, 108.58, 56.61, 41.28, 26.50. HRMS (ESI) m/z calculated for $[C_{27}H_{22}F_3NO+Na]^+$ 456.1542, found 456.1540.

**3-Benzyl-1-methyl-3-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)indolin-2-one (3az).** Isolated yield: 42%, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.35-7.32 (m, 2H), 7.31-7.27 (m, 2H), 7.24-7.18 (m, 3H), 7.10-7.04 (m, 4H), 6.87 (dd, *J* = 7.5, 2.5 Hz, 2H), 6.60 (d, *J* = 8.0 Hz, 1H), 6.57 (d, *J* = 10.5 Hz, 1H), 6.42 (d, *J* = 15.5 Hz, 1H), 6.23 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.50-5.44 (m, 1H), 3.20 (d, *J* = 13.0 Hz, 1H), 3.09 (d, *J* = 13.0 Hz, 1H), 2.97 (s, 3H), 2.85-2.75 (m, 2H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 143.67, 137.27, 135.85, 134.29, 131.32, 130.68, 129.85, 128.66, 128.52, 128.31, 127.87, 127.48, 127.31, 126.39, 126.18, 123.75, 121.99, 107.75, 54.72, 43.29, 40.32, 25.85. HRMS (ESI) m/z calculated for $[C_{27}H_{25}NO+H]^+$ 380.2003, found 380.2000.

**6-methoxy-1-methyl-3-phenyl-3-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)indolin-2-one (3a1).** Total isolated yield: 95%, 2*E*/2*Z* = 16.7:1. Purified **3a1**, colorless oil. $^1$H NMR (600 MHz, $CDCl_3$) δ 7.46-7.42 (m, 2H), 7.36-7.32 (m, 4H), 7.32-7.28 (m, 3H), 7.23-7.18 (m, 2H), 6.66 (dd, *J* = 8.4, 2.4 Hz, 1H), 6.58 (dd, *J* = 15.6, 10.8 Hz, 1H), 6.51 (d, *J* = 2.4 Hz, 1H), 6.42 (d, *J* = 15.6 Hz, 1H), 6.22 (dd, *J* = 15.0, 10.8 Hz, 1H), 5.47-5.40 (m, 1H), 3.89 (s, 3H), 3.20 (s, 3H), 3.17 (dd, *J* = 14.4, 6.0 Hz, 1H), 3.04 (dd, *J* = 14.4, 8.4

Hz, 1H).$^{13}$C NMR (150 MHz, $CDCl_3$) δ 178.49, 160.25, 145.06, 139.70, 137.29, 134.53, 131.42, 128.64, 128.56, 128.54, 127.36, 127.32, 127.14, 126.21, 125.89, 123.43, 106.37, 96.20, 56.16, 55.53, 41.37, 26.45.

**7-fluoro-1-methyl-3-phenyl-3-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)indolin-2-one (3a2)**. Total isolated yield: 92%, 2*E*/2*Z* = 8:1. Purified **3a2**, pale yellow oil.$^1$H NMR (500 MHz, $CDCl_3$) δ 7.41-7.38 (m, 2H), 7.36-7.33 (m, 4H), 7.32-7.28 (m, 3H), 7.24-7.19 (m, 1H), 7.09-7.05 (m, 3H), 6.58 (dd, *J* = 15.5, 10.5, 1H), 6.43 (d, *J* = 16.0 Hz, 1H), 6.22 (dd, *J* = 15.0, 10.5Hz, 1H), 5.44-5.37 (m, 1H), 3.44 (d, *J* = 2.8 Hz, 3H), 3.19-3.08 (m, 2H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 177.59, 147.88 (d, $^1J$ = 242.4 Hz), 138.98, 137.17, 134.95, 134.58 (d, $^4J$ = 3.0 Hz), 131.78, 130.54 (d, $^3J$ = 8.1 Hz), 128.67, 128.56, 128.40, 127.63, 127.52 (d, $^2J$ = 16.9 Hz), 126.98, 126.25, 122.97 (d, $^3J$ = 6.3 Hz), 121.06, 121.03, 116.24 (d, 2J = 19.0 Hz), 57.01, 41.22, 28.90 (d, *J* = 6.3 Hz).

**1-Methyl-3-(3-methylbenzyl)-3-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)indolin-2-one (3ba)**. Isolated yield: 35 %, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.35-7.31 (m, 2H), 7.29-7.26 (m, 2H), 7.23-7.17 (m, 3H), 7.06 (td, *J* = 7.5, 1.0 Hz, 1H), 6.95 (t, *J* = 7.5 Hz, 1H), 6.88 (d, *J* = 7.5 Hz, 1H), 6.71-6.65 (m, 2H), 6.63-6.54 (m, 2H), 6.41 (d, *J* = 15.5 Hz, 1H), 6.25-6.18 (m, 1H), 5.51-5.43 (m, 1H), 3.15 (d, *J* = 13.0 Hz, 1H), 3.06 (d, *J* = 13.0 Hz, 1H), 2.98 (s, 3H), 2.85-2.73 (m, 2H), 2.17 (s, 3H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 178.69, 143.74, 137.33, 136.96, 135.78, 134.26, 131.29, 130.83, 130.72, 128.72, 128.53, 128.43, 127.82, 127.33, 127.30, 127.08, 126.94, 126.19, 123.87, 121.89, 107.71, 54.63, 43.26, 40.24, 25.85, 21.18. HRMS (ESI) m/z calculated for $[C_{28}H_{27}NO+H]^+$ 394.2165, found 394.2165.

**Ethyl (4E,6E)-2-cyano-2,7-diphenylhepta-4,6-dienoate(3bb).** Total isolated yield: 96%, 2*E*/2*Z* = 10.0:1. Purified **3bb**, pale yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.61-7.57 (m, 2H), 7.47-7.43 (m, 2H), 7.42-7.37 (m, 3H), 7.32-7.30 (m, 2H), 7.26-7.22 (m, 1H), 6.74 (dd, *J* = 15.5, 10.5 Hz, 1H), 6.54 (d, *J* = 16.0 Hz, 1H), 6.40 (dd, *J* = 15.0, 10.5 Hz, 1H), 5.74 (dt, *J* = 15.0, 7.5 Hz, 1H), 4.32-4.22 (m, 2H), 3.23 (ddd, *J* = 14.0, 7.5, 1.0 Hz, 1H), 2.96 (ddd, *J* = 14.0, 7.0, 1.5 Hz, 1H), 1.27 (t, *J* = 7.0 Hz, 3H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 167.14, 137.01, 136.39, 134.14, 133.01, 129.16, 128.93, 128.59, 128.02, 127.66, 126.40, 126.15, 125.66, 118.10, 63.28, 54.46, 41.63, 13.87. HRMS (ESI) m/z calculated for $[C_{22}H_{21}NO_2+Na]^+$ 354.1465, found 354.1469.

**2-Methyl-2-((2E,4E)-5-phenylpenta-2,4-dien-1-yl)cyclopent-ane-1,3-dione(3bc).** Total isolated yield: 95%, 2*E*/2*Z*= 5.3:1. Purified **3bc**, yellow oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.39-7.35 (m, 2H), 7.31 (dd, *J* = 8.5, 7.0 Hz, 2H), 7.25-7.20 (m, 1H), 6.67 (ddd, *J* = 15.5, 10.5, 1.0 Hz, 1H), 6.49 (d, *J* = 15.5 Hz, 1H), 6.23 (ddd, *J* = 15.0, 10.5, 1.0Hz, 1H), 5.62-5.54 (m, 1H), 2.79-2.68 (m, 4H), 2.46 (dd, *J* = 8.0, 1.5 Hz, 2H), 1.15 (s, 3H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 216.25, 137.03, 135.27, 132.53, 128.60, 127.99, 127.62, 126.73, 126.33, 57.11, 39.10, 35.41, 18.89. HRMS (ESI) m/z calculated for $[C_{17}H_{18}O_2+H]^+$ 255.1380, found 255.1384.

**1-Methyl-3-phenyl-3-(5-phenylpentyl)indolin-2-one (5).** 89%, colorless oil. $^1$H NMR (500 MHz, $CDCl_3$) δ 7.37-7.29 (m, 3H), 7.29-7.27 (m, 1H), 7.26-7.19 (m, 5H), 7.16-7.07 (m, 4H), 6.89 (d, *J* = 8.0 Hz, 1H), 3.20 (s, 3H), 2.49 (t, *J* = 8.0, 2H), 2.36 (td, *J* = 13.0, 4.5 Hz, 1H), 2.17 (td, *J* = 13.0, 4.5 Hz, 1H), 1.55-1.47 (m, 2H), 1.35-1.20 (m, 3H), 1.18-1.08 (m, 1H), 0.97-0.86 (m, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 178.63, 142.51, 132.35, 128.45, 128.32, 128.17, 128.06, 127.16, 126.85, 125.56, 124.72, 122.53, 108.19, 56.69, 37.85, 35.75, 31.00, 29.28, 26.31, 24.33. HRMS (ESI) m/z calculated for $[C_{26}H_{27}NO+H]^+$ 370.2165, found 370.2174.

**2-Benzyl-4-(1-methyl-2-oxo-3-phenylindolin-3-yl)methyl)-7-phenyl-hexahydro-1H-isoindole-1,3(2H)-dione (6a).** Total isolated yield of **6a** and **6b**: 68%, **6a**:**6b** = 1.4:1. Purified **6a**, white solid, 194–196 °C; $^1$H NMR (500 MHz, $CDCl_3$) δ 7.51-7.46 (m, 2H), 7.40-7.32 (m, 4H), 7.32-7.26 (m, 9H), 7.16 (td, *J* = 7.5, 1.0 Hz, 1H), 7.08-7.03 (m, 2H), 6.92 (d, *J* = 7.5 Hz, 1H), 6.07 (dt, *J* = 9.5, 3.0 Hz, 1H), 6.04 (dt, *J* = 9.5, 3.0 Hz, 1H), 4.56 (d, *J* = 14.0 Hz, 1H), 4.46 (d, *J* = 14.0 Hz, 1H), 3.29-3.20 (m, 5H), 3.16-3.10 (m, 2H), 2.84 (dd, *J* = 8.5, 5.5 Hz, 1H), 2.07-2.02 (m, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 178.25, 176.84, 175.39, 143.88, 140.16, 138.78, 135.87, 134.34, 131.79, 130.03, 128.63, 128.59, 128.58, 128.41, 128.12, 127.71, 127.44, 126.99, 126.94, 124.98, 122.83, 108.36, 56.52, 46.73, 45.30, 42.06, 41.43, 39.32, 33.43, 26.43. HRMS (ESI) calculated for $[C_{37}H_{32}N_2O_3+H]^+$ 553.2486, found 553.2482.

**2-Benzyl-4-(1-methyl-2-oxo-3-phenylindolin-3-yl)methyl)-7-phenyl-hexahydro-1H-isoindole-1,3(2H)-dione (6b).** Total isolated yield of **6a** and **6b**: 68%, **6a**:**6b** = 1.4:1. Purified **6b**, white solid, 210-212 °C; $^1$H NMR (500 MHz, $CDCl_3$) δ 7.51-7.47 (m, 2H), 7.38-7.26 (m, 13H), 7.14 (td, *J* = 7.5, 1.0 Hz, 1H), 7.06-7.02 (m, 2H), 6.89 (d, *J* = 7.5 Hz, 1H), 5.83 (dt, *J* = 9.5, 3.5 Hz, 1H), 5.35 (dt, *J* = 9.5, 3.5 Hz, 1H), 4.56 (d, *J* = 14.0 Hz, 1H), 4.46 (d, *J* = 14.0 Hz, 1H), 3.41-3.37 (m, 1H), 3.33 (dd, *J* = 14.5, 2.5 Hz, 1H), 3.27 (s, 3H), 3.24 (t, *J* = 8.0Hz, 1H), 3.17 (dd, *J* = 8.5, 5.0 Hz, 1H), 3.09 (dd, *J* = 14.5, 10.0 Hz, 1H), 2.31-2.25 (m, 1H). $^{13}$C NMR (125 MHz, $CDCl_3$) δ 178.49, 177.11, 175.39, 143.56, 140.28, 138.72, 135.91, 133.81, 132.07, 129.42, 128.67, 128.65, 128.54, 128.48, 128.40, 128.14, 127.71, 127.44, 126.95, 126.78, 125.32, 122.77, 108.53, 56.99, 46.67, 46.11, 42.07, 41.49, 39.34, 34.04, 26.45. HRMS (ESI) calculated for $[C_{37}H_{32}N_2O_3+Na]^+$ 575.2305, found 575.2313.

## Acknowledgments

Financial support from the National Natural Science Foundation of China (21402175, 21875219) is acknowledged.

**Keywords:** Palladium • Allylation • 1,3-Diene • C-C Bond cleavage • Quaternary stereocenter

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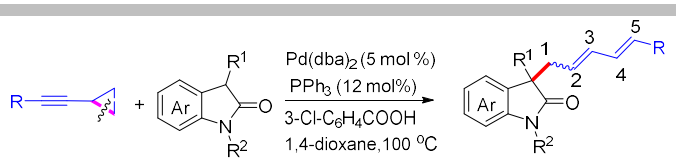


C-C bond Cleavage
Linear and *E*-selectivity
100% atom-economy

A novel palladium-catalyzed allylic alkylation of oxindoles with cyclopropyl acetylenes has been developed. Various 1,3-diene oxindole framework bearing a quaternary stereocenter at the C3 position were synthesized straightforwardly in good to excellent yields with high regio-, and stereoselectivities.

**Palladium-Catalyzed Allylation of Cyclopropyl Acetylenes with Oxindoles to Construct 1,3-Dienes**

*Chuan-Jun Lu,* Xin Yu, Yu-Ting Chen, Qing-Bao Song,* Zhen-Ping Yang, Hong Wang*

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