Synthesis X. Zhang et al. Paper

Metal-Free Blue-Light-Mediated Cyclopropanation of Indoles by Aryl(diazo)acetates

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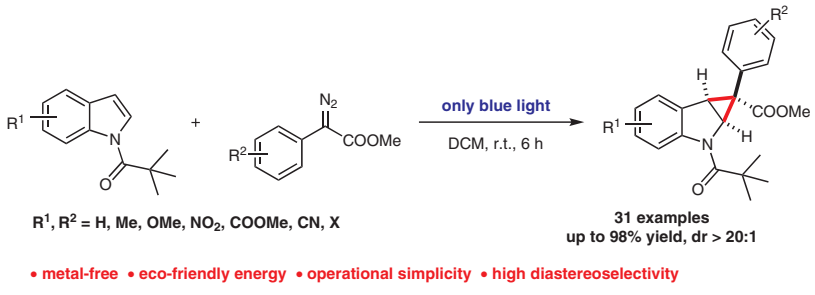

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Abstract Blue-light-mediated cyclopropanation of indoles with aryl(diazo)acetates has been developed. The salient features of this strategy are that it is metal-free, operationally simple and atom-efficient, and that it uses an environmentally friendly energy source. In this protocol, blue light was employed as the sole energy source for the transformation. A variety of cyclopropane-fused indoline compounds was obtained in moderate to excellent yields and high diastereoselectivities under mild conditions.

Key words metal-free, blue light, cyclopropanation, indoles, diazo compounds, aryl(diazo)acetate

Cyclopropane-fused indolines represent an important and versatile structure commonly existing in many medicinal agents[1] and natural products.[2] These structural units have substantial utilities in the synthesis of indole-containing polycyclic compounds and indole alkaloids, such as lundurine A–C (Figure 1).[3] Typically, strategies for the construction of indolines containing a cyclopropane moiety strongly rely on transition-metal-catalyzed [2+1] cycloadditions of indoles with diazo compounds[1e,4] or tosylhydrazones.[5] Cyclopropanation of indoles with metal carbenes to construct these structural units have been reported recently by Zhou,[6] Pirovano,[7] and other groups[4,5,8] (Scheme 1). Noteworthy is that transition-metal catalysts were essential in the above strategies, while metal-free approaches were reported only rarely; this makes the available protocols relatively unattractive from a sustainable perspective.

In sharp contrast, photochemistry has been widely developed in green organic synthesis due to its characteristics of operational simplicity, lower energy consumption, and higher atom economy.[9] Photocatalysts, commonly derived from transition-metal complexes or organic dyes,[10] are generally unavoidable as radical initiators in these strategies. In comparison, photocatalyst-free strategies,[9d,11] only mediat-

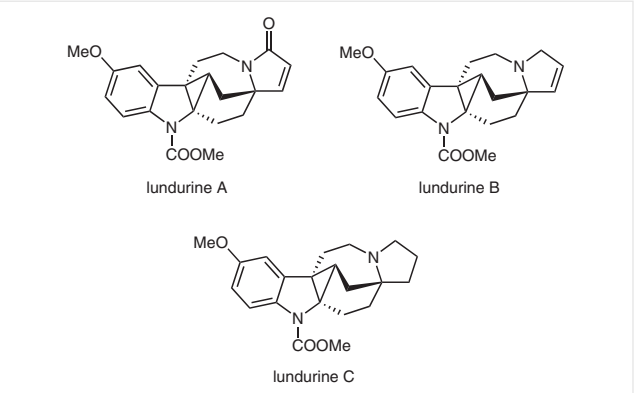
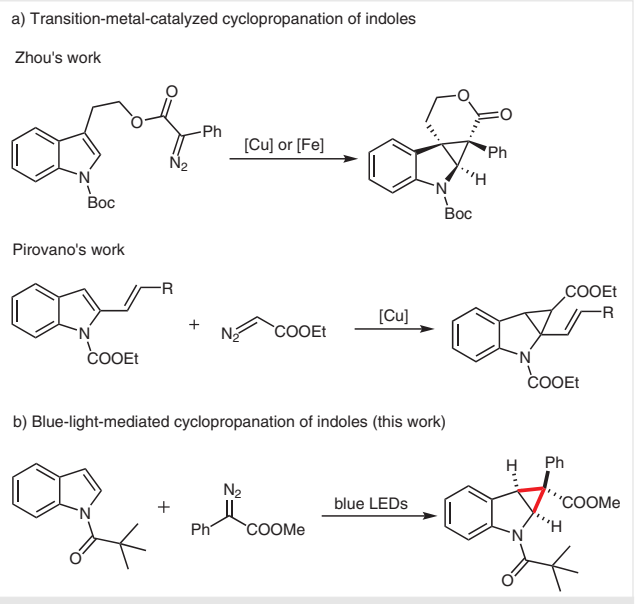


Figure 1 Selected indole-containing alkaloids



Scheme 1 Different routes for cyclopropanation of indole

ed by visible light, are more interesting from a synthetic perspective; notable achievements have been accomplished for C–H and N–H insertion,[11a] intramolecular C(sp^3)–H imination,[11b] and cross-coupling of diazoacetates[11c] under visible-light irradiation without the use of other additives. Such protocols are generally operationally simpler and proceed under milder conditions, in which visible light is harnessed as the only energy source.

Despite the indisputable advances, the photocatalyst-free cyclopropanation of indoles mediated by visible light has been rarely reported. Inspired by the aforementioned progress, we attempted to search for an efficient and sustainable protocol to construct this structure in the absence of metal salt and other additives. Hence, a blue-light-mediated strategy for a facile access to cyclopropanated indole is reported. Salient features of this approach include (a) synthetic simplicity, atom efficiency, and an eco-friendly energy source, (b) moderate to excellent yields and high diastereoselectivities, and (c) broad functional group scope of substituted indoles and aryl(diazo)acetates.

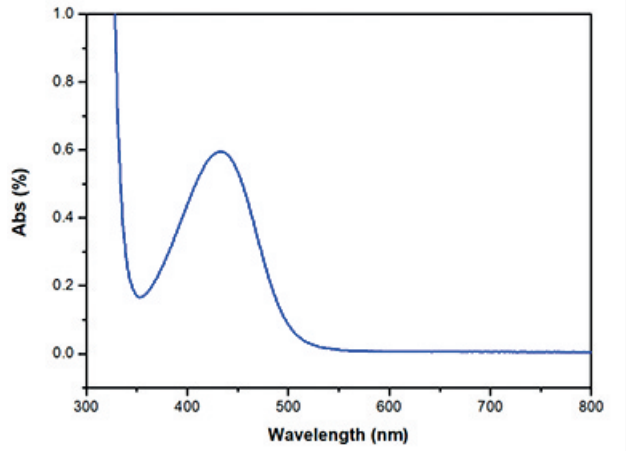
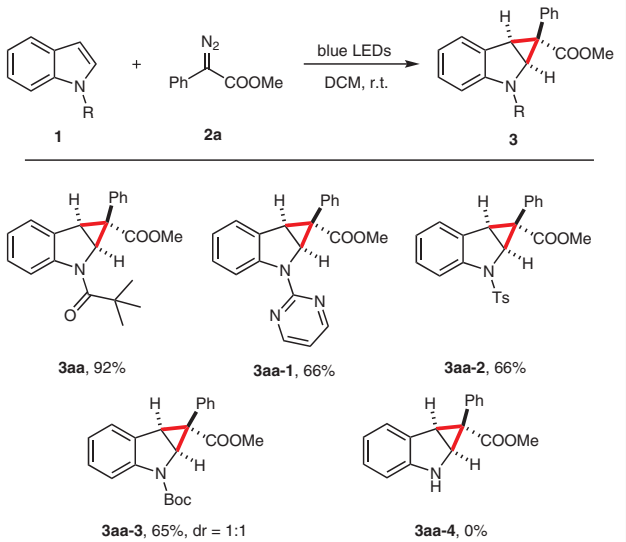


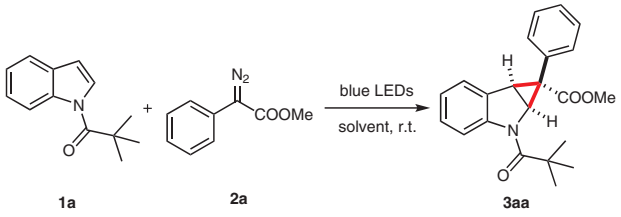
Figure 2 UV-vis absorbance spectrum of **2a** in DCM (0.2 mol/mL)



Scheme 2 Investigation of protecting groups R (dr >20:1)

Our investigation commenced with the analysis of the UV-vis absorbance spectrum of aryl(diazo)acetate **2a**, which exhibits absorbance in the visible region (Figure 2). According to the literature, the emission spectrum of blue LEDs is from 420 nm to 510 nm, indicating that **2a** might be activated under the irradiation of blue LEDs. With this in mind, we screened various protecting groups (pivaloyl, pyrimidin-2-yl, tosyl, Boc) and pivaloyl emerged as the optimal group, giving **3aa** in 92% yield and excellent diastereoselectivities (dr >20:1) (Scheme 2). The structure of **3aa** was confirmed by single-crystal X-ray crystallography.[12] Then various solvents were screened for the reaction (Table 1). DCM was found to perform best (entry 1). The solvents $PhCF_3$, $CHCl_3$, DCE, and MeCN gave slightly inferior results (entries 2–5) and THF, dioxane, DMF, HFIP, and DMSO in-

Table 1 Optimization of Reaction Conditions[a]

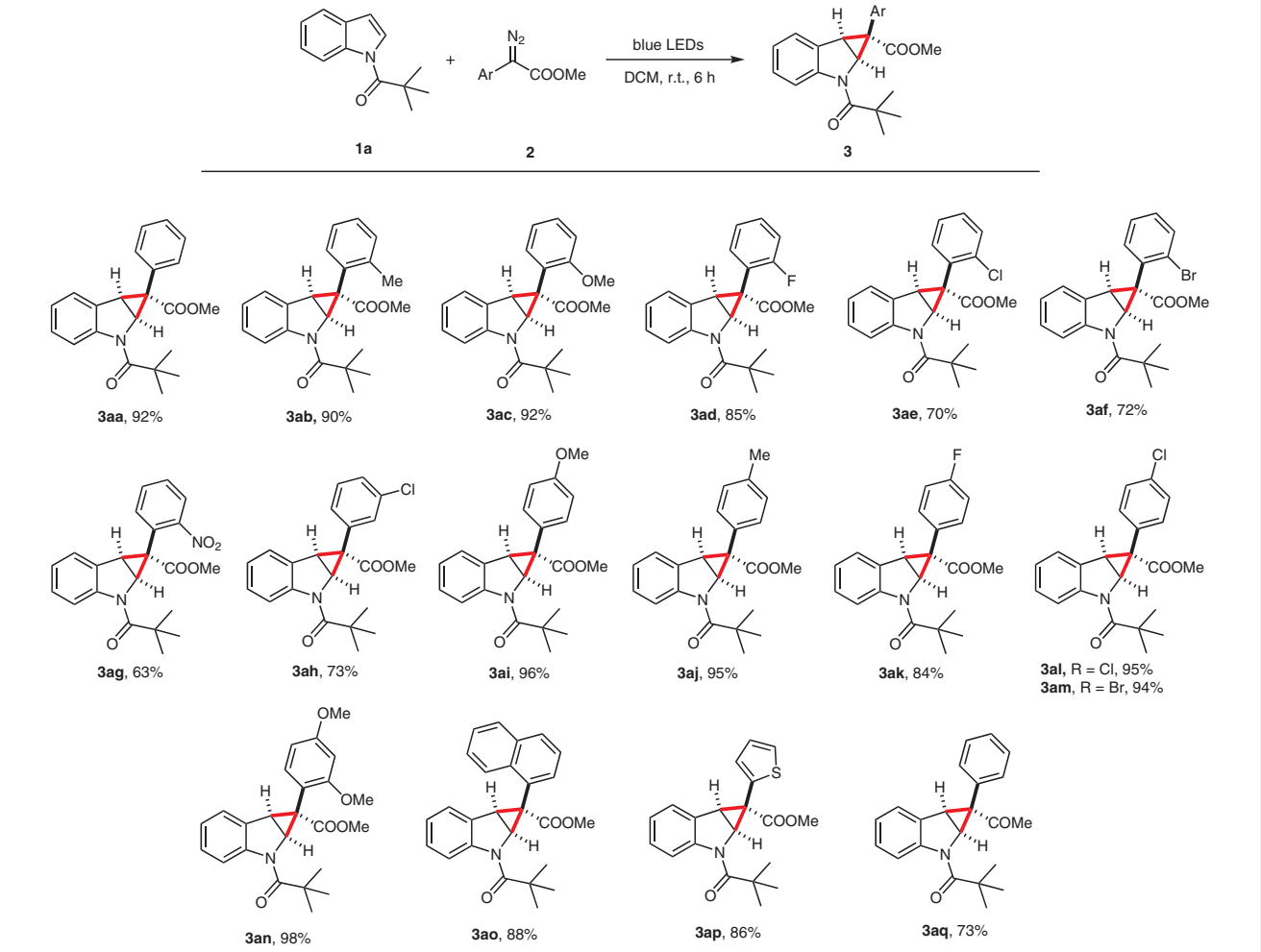


Entry	Solvent	Time (h)	Yield (%)[b]
1	DCM	12	92
2	$PhCF_3$	12	85
3	$CHCl_3$	12	86
4	DCE	12	69
5	MeCN	12	72
6	THF	12	7
7	1,4-dioxane	12	N.R.
8	DMF	12	N.R.
9	HFIP	12	N.R.
10	DMSO	12	N.R.
11	DCM	10	92
12	DCM	8	92
13	**DCM**	**6**	**92**
14	DCM	4	76
15[c]	DCM	6	54
16[d]	DCM	6	0

[a] Reaction conditions: **1a** (0.2 mmol), **2a** (0.4 mmol), blue light (9 W), solvent (1 mL), air atmosphere, r.t., 12 h.
[b] Isolated yield (unless mentioned otherwise, dr >20:1); N.R. = No Reaction.
[c] Green LEDs.
[d] In the dark.

hibited the cyclopropanation of indole (entries 6–10). Subsequently, reaction time was investigated. The best results were obtained after 6 hours, with longer reaction times not improving the results (entries 11–14). However, when we replaced the light source with green LEDs, the yield dropped significantly (54%, entry 15); without light, in the dark, no **3aa** was detected (entry 16). This indicates that blue light is essential in this strategy. Changing the relative amounts of substrates and solvent did not increase the cyclopropanation yield further (see the Supporting Information).

Having optimized the reaction conditions, we explored the scope of the reaction of **1a** with various aryl(diazo)acetates **2** (Scheme 3). A broad variety of substituted aryl(diazo)acetates were compatible with this blue-light-mediated method for the cyclopropanation of indoles, regardless of the electronic properties of the substrates. Halo- and nitro-substituted substrates were well tolerated, giving the corresponding products in yields of 63–95% (**3ad–ah**, **3ak–am**), providing the possibility for further applications. Substrates with electron-donating groups, such as methyl and methoxy substituents at the *ortho* position of the phenyl ring, provided the corresponding cyclopropanation products **3ab** and **3ac** in 90 and 92% yield with excellent diastereoselectivities under blue light irradiation. Phenyl(diazo)acetates with methoxy and methyl groups the at the *para* position gave the corresponding products **3ai** and **3aj** in 96 and 95% yield, respectively. Additionally, disubstituted substrate **2n** afforded the cyclopropane product **3an** in excellent yield (98%). Moreover, naphthalene (**2o**) and thiophene substrates (**2p**) were also suitable for this reaction, affording the cycloaddition products in 88 and 86% yield, respectively. When we replaced the electron-withdrawing carboxy group (COOMe) of aryl(diazo)acetate with acyl (COMe), the target product was also obtained in 73% yield (**3aq**). On the other hand, 2-diazo-1,2-diphenylethanone, 2-diazo-2-phe-

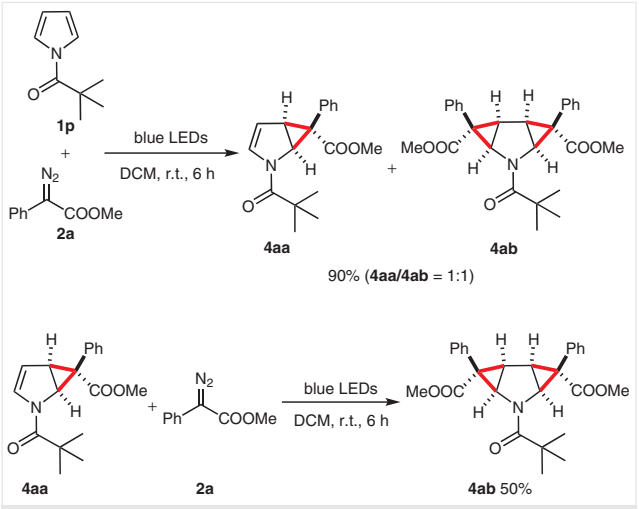


Scheme 3 Substrate scope of aryl(diazo)acetates (dr >20:1)

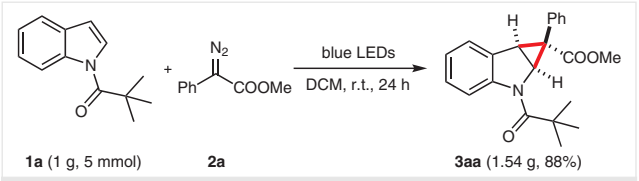
nylacetonitrile and diethyl 2-diazomalonate were not compatible with this reaction system and did not deliver the corresponding cyclopropanation products.

Next, we investigated the scope of indole substrates. A variety of indoles proceed smoothly under the optimized conditions to afford the corresponding cyclopropane products in moderate to excellent yields and high diastereoselectivities. The results are shown in Scheme 4. Substrates bearing the electron-donating groups methyl and methoxy (**1d** and **1e**) were compatible with this reaction procedure, giving the corresponding cyclopropane products **3da** and **3ea** in 69 and 76% isolated yield, respectively. Nitro- (**1i**), cyano- (**1j** and **1m**), and methoxycarbonyl-substituted (**1k**, **1n**) indoles were also tolerated in the cycloaddition reaction, giving the desired products in good to high yields (76–86%). For substrates bearing fluoro (**1f**, **1l**, **1o**), chloro (**1b**, **1g**), and bromo (**1c**, **1h**) groups, the cyclopropanation reaction was also found to proceed smoothly in 78–95% yield (**3ba**, **3ca**, **3fa–ha**, **3la**, **3oa**).

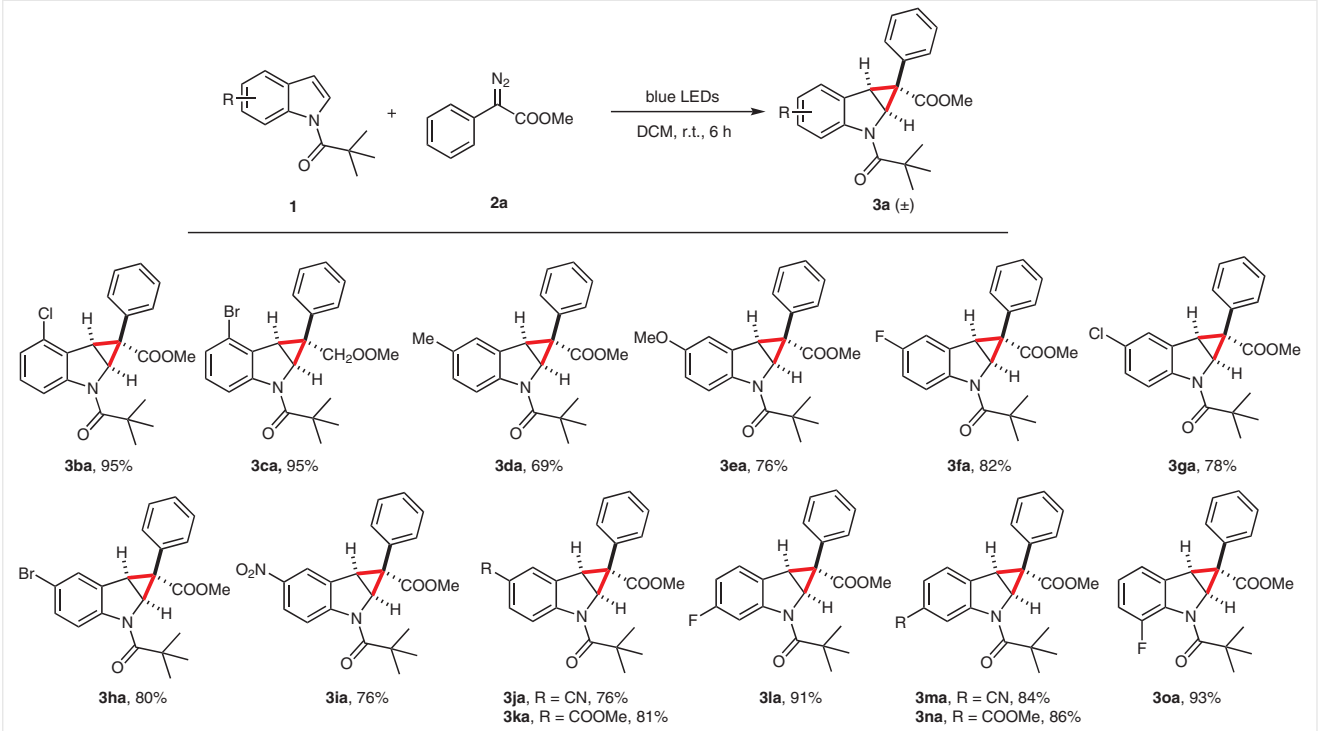
Furthermore, when *N*-pivaloylpyrrole (**1p**) was employed, both monocyclopropane (**4aa**) and bicyclopropane (**4ab**) products were obtained in a 1:1 ratio under the optimized reaction conditions (Scheme 5). The monocyclopropane product were subsequently converted into the bicyclopropane product in 50% yield in the presence of aryl(diazo)acetate **2a** (Scheme 5). Unfortunately, when reactions with thiophene and furan were attempted, no cyclopropane products were detected.



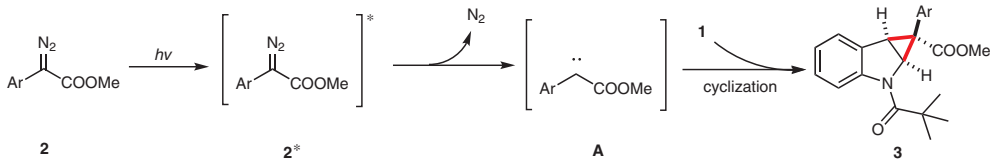
Scheme 5 Cyclopropanation of pyrrole with **2a**



Scheme 6 Gram-scale experiment



Scheme 4 Substrate scope of indoles (dr >20:1)



Scheme 7 Plausible mechanism

To further demonstrate the broad application of the current protocol, a gram-scale reaction of **1a** with **2a** was carried out for 24 hours to afford product **3aa** in 88% yield with excellent diastereoselectivity (dr >20:1) (Scheme 6). Subsequently, a 3-substituted indole derivative was obtained by simple base hydrolysis (see Supporting Information for details).

Finally, on account of the character of the aryl(diazo)acetates **2**, a plausible mechanism for the blue-light-induced cyclopropanation reaction was proposed based on our experiments and the relevant literature (Scheme 7).[11a,11c,13] Firstly, excited state **2*** is generated via a photoexcitation process of aryl(diazo)acetate **2**; then N_2 is released to afford singlet-state intermediate carbene **A**. Then the singlet-state carbene **A** is trapped by *N*-pivaloylindole **1** to give the cyclopropanation product **3**.

In conclusion, we have developed a metal-free strategy for constructing cyclopropane-fused indolines mediated by blue light under ambient temperature conditions. This cyclopropanation protocol displays operational simplicity, with blue light utilized as the sole energy source, to provide a variety of cyclopropane-fused indoline compounds in moderate to excellent yields and high diastereoselectivities under mild conditions. A gram-scale experiment was also conducted to further demonstrate the applicability of this strategy; the desired product was obtained in high yield and diastereoselectivity. The notable features of this protocol include that it operates under transition-metal- and photocatalyst-free conditions, while also being atom-economical and environmentally friendly.

Unless mentioned otherwise, all materials and solvents were commercially obtained and used without further purification and all the experiments were performed under ambient air. ^{1}H NMR, ^{13}C NMR, and ^{19}F NMR spectra were respectively recorded at 400 MHz, 101 MHz, and 376 MHz on a Bruker DPX instrument using Me_4Si as an internal standard. HRMS for new compounds was carried out on a Waters Q-Tof Micro MS/MS System ESI spectrometer. Melting points were measured on a WC-1 instrument and are uncorrected. All the indole[14] and aryl(diazo)acetate[15] substrates were prepared according to literature procedures.

Cyclopropanation of Indoles; General Procedure

N-Substituted indole **1** (0.2 mmol), aryl(diazo)acetate **2** (0.4 mmol), and anhyd DCM (1 mL) were added to a 15 mL oven-dried Schlenk tube equipped with a stir bar under ambient air. Then the reaction was stirred under blue LED irradiation. After completion of the reaction, the mixture was purified by preparative TLC on silica gel. Unless mentioned otherwise, dr >20:1.

Gram-Scale Synthesis of Product 3aa

N-Pivaloylindole (**1a**; 1 g, 5 mmol), methyl phenyl(diazo)acetate (**2a**; 1.8 g, 10 mmol) were added to anhyd DCM (25 mL) under ambient air. Then the mixture was stirred under 9 W blue LED irradiation for 24 h. After completion of the reaction, the mixture was concentrated under vacuum and the residue was purified by flash chromatography (PE–EtOAc, 20:1) to afford **3aa**; yield: 1.54 g (88%); white solid.

Methyl 1-Phenyl-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3aa)[12]

Yield: 64.2 mg (92%); white solid; mp 155–156 °C; R_f = 0.59 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.84–7.78 (m, 1 H), 7.37 (dd, *J* = 7.2, 1.5 Hz, 1 H), 7.06–6.99 (m, 3 H), 6.99–6.91 (m, 4 H), 5.20 (d, *J* = 7.0 Hz, 1 H), 3.83 (d, *J* = 7.0 Hz, 1 H), 3.69 (s, 3 H), 1.56 (s, *J* = 2.8 Hz, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.0, 173.4, 144.1, 131.8, 129.9, 128.4, 127.9, 127.6, 127.3, 125.0, 123.5, 117.8, 53.0, 51.8, 40.8, 36.7, 28.2.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{24}NO_3$: 350.1751; found: 350.1754.

Methyl 6-Chloro-1-phenyl-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ba)

Yield: 72.9 mg (95%); white solid; mp 165–166 °C; R_f = 0.55 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.71 (dd, *J* = 6.9, 2.2 Hz, 1 H), 7.09–7.04 (m, 3 H), 7.02 (dd, 2 H), 6.94–6.86 (m, 2 H), 5.20 (d, *J* = 7.0 Hz, 1 H), 3.93 (d, *J* = 7.0 Hz, 1 H), 3.71 (s, 3 H), 1.56 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.1, 173.1, 145.2, 131.4, 130.7, 129.8, 129.2, 127.9, 127.6, 127.4, 123.4, 116.0, 53.1, 53.1, 51.8, 51.7, 40.9, 35.5, 35.5, 32.3, 28.1.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{23}ClNO_3$: 384.1361; found: 384.1362.

Methyl 6-Bromo-1-phenyl-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ca)

Purified by preparative TLC (silica gel, PE–EtOAc, 5:1; R_f = 0.55); yield: 81.4 mg (95%); white solid; mp 162–163 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.76 (d, *J* = 8.2 Hz, 1 H), 7.11–6.99 (m, 6 H), 6.84 (t, *J* = 8.1 Hz, 1 H), 5.19 (d, *J* = 7.0 Hz, 1 H), 3.89 (d, *J* = 7.0 Hz, 1 H), 3.71 (s, 3 H), 1.55 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.1, 173.1, 144.9, 131.5, 129.8, 129.4, 129.4, 127.9, 127.5, 126.4, 119.5, 116.5, 53.2, 53.1, 51.5, 51.5, 40.9, 37.4, 37.3, 32.2, 28.1.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{23}BrNO_3$: 428.0856; found: 428.0859.

Methyl 5-Methyl-1-phenyl-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3da)

Yield: 50.2 mg (69%); white solid; mp 170–171 °C; R_f = 0.47 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.68 (d, *J* = 8.4 Hz, 1 H), 7.16 (s, 1 H), 7.07–7.00 (m, 3 H), 6.97–6.93 (m, 2 H), 6.79 (d, *J* = 7.2 Hz, 1 H), 5.17 (d, *J* = 7.0 Hz, 1 H), 3.77 (d, *J* = 7.0 Hz, 1 H), 3.69 (s, 3 H), 2.26 (s, 3 H), 1.54 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 176.7, 173.4, 141.9, 133.2, 131.7, 130.0, 128.5, 128.4, 127.6, 127.2, 125.5, 125.4, 117.5, 53.0, 52.9, 52.0, 52.0, 40.7, 36.7, 36.6, 32.5, 28.2, 20.9, 20.9.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{23}H_{26}NO_3$: 364.1907; found: 364.1909.

Methyl 5-Methoxy-1-phenyl-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ea)

Yield: 57.7 mg (76%); white solid; mp 169–170 °C; R_f = 0.33 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.73 (d, *J* = 9.0 Hz, 1 H), 7.08–7.03 (m, 3 H), 6.99 (m, 2 H), 6.93 (d, *J* = 2.7 Hz, 1 H), 6.52 (dd, *J* = 9.0, 2.7 Hz, 1 H), 5.18 (d, *J* = 6.9 Hz, 1 H), 3.78 (d, *J* = 6.9 Hz, 1 H), 3.74 (s, 3 H), 3.68 (s, 3 H), 1.55 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 176.4, 173.3, 156.2, 138.0, 131.6, 129.9, 129.7, 127.7, 127.3, 118.5, 112.7, 111.1, 55.7, 55.7, 53.0, 52.9, 52.1, 52.1, 40.6, 36.6, 36.6, 32.8, 28.3.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{23}H_{26}NO_4$: 380.1857; found: 380.1860.

Methyl 5-Fluoro-1-phenyl-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3fa)

Yield: 60.3 mg (82%); white solid; mp 152–153 °C; R_f = 0.45 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.78 (dd, *J* = 9.1, 4.9 Hz, 1 H), 7.09–7.04 (m, 4 H), 7.00–6.94 (m, 2 H), 6.71–6.64 (m, 1 H), 5.21 (d, *J* = 6.9 Hz, 1 H), 3.80 (d, *J* = 6.9 Hz, 1 H), 3.69 (s, 3 H), 1.55 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 176.7, 173.1, 160.3(J_{C-F} = 242.17 Hz), 157.8, 140.2 (J_{C-F} = 1.46 Hz), 131.6, 130.1 (J_{C-F} = 8.80 Hz), 129.6, 127.8, 118.8 (J_{C-F} = 8.06 Hz), 114.3 (J_{C-F} = 22.76 Hz), 112.1 (J_{C-F} = 24.12 Hz), 53.1, 53.0, 52.2, 52.1, 40.7, 36.2, 32.4, 28.2.

^{19}F NMR (376 MHz, $CDCl_3$): δ = –119.14.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{23}FNO_3$: 368.1657; found: 368.1660.

Methyl 5-Chloro-1-phenyl-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ga)

Yield: 59.9 mg (78%); white solid; mp 184–185 °C; R_f = 0.33 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.75 (d, *J* = 8.8 Hz, 1 H), 7.33 (d, *J* = 2.2 Hz, 1 H), 7.09–7.04 (m, 3 H), 6.98–6.92 (m, 3 H), 5.20 (d, *J* = 7.0 Hz, 1 H), 3.79 (d, *J* = 6.9 Hz, 1 H), 3.69 (s, 3 H), 1.55 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 176.9, 173.1, 142.7, 131.6, 130.2, 129.6, 128.4, 127.9, 127.5, 124.9, 118.7, 53.1, 53.1, 52.0, 52.0, 40.8, 36.1, 36.1, 32.3, 28.2.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{23}ClNO_3$: 384.1361; found: 384.1362.

Methyl 5-Bromo-1-phenyl-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ha)

Yield: 68.5 mg (80%); white solid; mp 170–171 °C; R_f = 0.33 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.76 (d, *J* = 8.2 Hz, 1 H), 7.09–7.01 (m, 6 H), 6.84 (t, *J* = 8.1 Hz, 1 H), 5.19 (d, *J* = 7.0 Hz, 1 H), 3.89 (d, *J* = 7.0 Hz, 1 H), 3.71 (s, 3 H), 1.56 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 176.9, 173.1, 143.2, 131.6, 130.8, 130.6, 129.5, 127.9, 127.8, 127.5, 119.1, 115.9, 53.1, 53.1, 52.0, 51.9, 40.8, 36.1, 36.0, 32.2, 28.2.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{23}BrNO_3$: 428.0856; found: 428.0860.

Methyl 5-Nitro-1-phenyl-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ia)

Yield: 60.0 mg (76%); white solid; mp 225–226 °C; R_f = 0.31 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.23 (d, *J* = 2.0 Hz, 1 H), 7.95–7.85 (m, 2 H), 7.11–7.02 (m, 3 H), 6.99–6.92 (m, 2 H), 5.28 (d, *J* = 6.9 Hz, 1 H), 3.90 (d, *J* = 6.9 Hz, 1 H), 3.72 (s, 3 H), 1.57 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 176.9, 172.8, 144.0, 133.3, 132.2, 131.0, 129.4, 129.1, 128.3, 128.0, 124.9, 123.7, 121.6, 118.0, 53.0, 51.9, 40.8, 36.6, 31.7, 28.2.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{23}N_2O_5$: 395.1602; found: 395.1604.

Methyl 5-Cyano-1-phenyl-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ja)

Yield: 56.9 mg (76%); white solid; mp 225–226 °C; R_f = 0.26 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.89 (d, *J* = 8.6 Hz, 1 H), 7.62 (d, *J* = 1.6 Hz, 1 H), 7.28 (dd, *J* = 8.3, 1.4 Hz, 1 H), 7.10–7.03 (m, 3 H), 6.93 (m, 2 H), 5.24 (d, *J* = 7.0 Hz, 1 H), 3.85 (d, *J* = 7.0 Hz, 1 H), 3.71 (s, 3 H), 1.56 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.4, 172.8, 147.4, 132.6, 131.6, 129.7, 129.1, 128.6, 128.1, 127.7, 119.0, 118.0, 106.5, 53.3, 53.2, 52.0, 51.9, 41.1, 35.8, 35.7, 31.9, 28.1.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{23}H_{23}N_2O_3$: 375.1707; found: 375.1705.

Dimethyl 1-Phenyl-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1,5-dicarboxylate (3ka)

Yield: 66.0 mg (81%); white solid; mp 147–148 °C; R_f = 0.28 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.05 (d, *J* = 1.8 Hz, 1 H), 7.85 (d, *J* = 8.7 Hz, 1 H), 7.69 (dd, *J* = 8.7, 1.8 Hz, 1 H), 7.06–7.01 (dd, *J* = 6.5, 2.7 Hz, 3 H), 6.98–6.93 (m, 2 H), 5.23 (d, *J* = 7.0 Hz, 1 H), 3.88 (s, 3 H), 3.86 (d, *J* = 7.0 Hz, 1 H), 3.70 (s, 3 H), 1.57 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.3, 173.1, 166.6, 147.7, 131.7, 130.1, 129.5, 128.7, 127.9, 127.5, 126.4, 125.2, 117.0, 53.2, 53.1, 52.2, 52.2, 52.0, 52.0, 41.0, 36.2, 36.1, 32.1, 28.1.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{24}H_{26}NO_5$: 408.1806; found: 408.1809.

Methyl 4-Fluoro-1-phenyl-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3la)

Yield: 66.9 mg (91%); white solid; mp 155–156 °C; R_f = 0.42 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.59 (dd, *J* = 11.1, 2.4 Hz, 1 H), 7.29–7.23 (m, 1 H), 7.09–7.03 (m, 3 H), 6.96–6.93 (m,2 H), 6.72–6.65 (m, 1 H), 5.22 (d, *J* = 7.0 Hz, 1 H), 3.78 (d, *J* = 7.0 Hz, 1 H), 3.69 (s, 3 H), 1.55 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.1, 173.2, 163.6 ($J_{C–F}$ = 242.17 Hz), 161.2, 145.3, 131.7, 129.7, 127.8, 127.5, 124.1 ($J_{C–F}$ = 2.28 Hz), 110.5 ($J_{C–F}$ = 23.5 Hz), 106.1 ($J_{C–F}$ = 29.4 Hz), 53.0, 53.0, 52.6, 52.6, 40.8, 36.0, 36.0, 32.2, 28.1.

^{19}F NMR (376 MHz, $CDCl_3$): δ = –112.56.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{23}FNO_3$: 368.1657; found: 368.1658.

Methyl 4-Cyano-1-phenyl-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ma)

Yield: 62.9 mg (84%); white solid; mp 164–165 °C; R_f = 0.20 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.15 (d, *J* = 1.4 Hz, 1 H), 7.44 (d, *J* = 7.8 Hz, 1 H), 7.24 (dd, *J* = 7.8, 1.4 Hz, 1 H), 7.10–7.02 (m, 3 H), 6.93 (dd, *J* = 7.9, 1.6 Hz, 2 H), 5.25 (d, *J* = 6.9 Hz, 1 H), 3.86 (d, *J* = 6.8 Hz, 1 H), 3.71 (s, 3 H), 1.54 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.2, 172.8, 144.1, 133.6, 131.5, 129.1, 128.0, 127.8, 127.5, 125.6, 121.0, 118.8, 111.4, 53.3, 53.2, 52.0, 52.0, 40.9, 36.4, 36.3, 32.2, 28.1.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{23}H_{23}N_2O_3$: 375.4397; found: 375.4396.

Dimethyl 1-Phenyl-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1,4-dicarboxylate (3na)

Yield: 70.1 mg (86%); brown oil; R_f = 0.31 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.47 (d, *J* = 1.4 Hz, 1 H), 7.69 (dd, *J* = 7.8, 1.5 Hz, 1 H), 7.43 (d, *J* = 7.8 Hz, 1 H), 7.06–6.99 (m, 3 H), 6.98–6.92 (m, 2 H), 5.25 (d, *J* = 6.9 Hz, 1 H), 3.85 (d, *J* = 6.9 Hz, 1 H), 3.78 (s, 3 H), 3.70 (s, 3 H), 1.57 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.3, 173.1, 166.6, 147.7, 131.7, 130.1, 129.5, 128.7, 127.9, 127.5, 126.4, 125.2, 117.0, 53.2, 53.1, 52.2, 52.2, 52.0, 52.0, 41.0, 36.2, 36.1, 32.1, 28.1.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{24}H_{26}NO_5$: 408.1806; found: 408.1810.

Methyl 3-Fluoro-1-phenyl-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3oa)

Yield: 68.3 mg mg (93%); white solid; mp 157–158 °C; R_f = 0.34 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.17 (dd, *J* = 7.5, 0.7 Hz, 1 H), 7.06–7.01 (m, 3 H), 6.99–6.96 (m, 2 H), 6.95–6.88 (m, 1 H), 6.69 (ddd, *J* = 10.8, 8.3, 0.9 Hz, 1 H), 5.06 (d, *J* = 6.5 Hz, 1 H), 3.81 (d, *J* = 6.5 Hz, 1 H), 3.68 (s, 3 H), 1.58 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.1, 173.1, 144.9, 131.5 ($J_{C–F}$ = 242.42 Hz), 129.8 ($J_{C–F}$ = 26.53 Hz), 129.4, 129.4, 127.9, 127.5 ($J_{C–F}$ = 22.98 Hz), 126.4, 119.5 ($J_{C–F}$ = 2.39 Hz), 116.5, 53.2, 53.1, 51.5, 51.5, 40.9, 37.4, 37.3, 32.2, 28.1.

^{19}F NMR (565 MHz, $CDCl_3$): δ = –109.89.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{23}FNO_3$: 368.1657; found: 368.1660.

Methyl 2-Pivaloyl-1-(*o*-tolyl)-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ab)

Yield: 65.4 mg (90%); white solid; mp 300–301 °C; R_f = 0.56 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.89 (d, *J* = 8.3 Hz, 1 H), 7.30 (d, *J* = 7.2 Hz, 1 H), 7.03–6.93 (m, 3 H), 6.90 (d, *J* = 7.04 Hz, 1 H), 6.85 (dd, *J* = 13.2, 6.8 Hz, 2 H), 5.15 (d, *J* = 7.0 Hz, 1 H), 3.91 (d, *J* = 7.0 Hz, 1 H), 3.70 (s, 3 H), 2.20 (s, 3 H), 1.58 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 176.7, 173.4, 141.9, 133.2, 131.7, 130.0, 128.5, 128.4, 127.6, 127.2, 125.5, 125.4, 117.5, 53.0, 52.9, 52.0, 52.0, 40.7, 36.7, 36.6, 32.5, 28.2, 20.9, 20.9.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{23}H_{26}NO_3$: 364.1907; found: 364.1910.

Methyl 1-(2-Methoxyphenyl)-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ac)

Yield: 69.8 mg (92%); white solid; mp 163–164 °C; R_f = 0.44 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.84 (d, *J* = 8.2 Hz, 1 H), 7.24 (d, *J* = 8.3 Hz, 1 H), 7.04–6.98 (m, 1 H), 6.97–6.91 (m, 2 H), 6.84 (t, *J* = 7.0 Hz, 1 H), 6.64 (t, *J* = 7.1 Hz, 1 H), 6.52 (d, *J* = 7.9 Hz, 1 H), 5.12 (d, *J* = 6.9 Hz, 1 H), 3.87 (d, *J* = 6.8 Hz, 1 H), 3.69 (s, 3 H), 3.68 (s, 3 H), 1.56 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.00, 173.65, 158.39, 144.19, 130.78, 129.04, 128.40, 127.60, 124.69, 122.86, 119.56, 118.80, 117.26, 109.89, 55.06, 55.02, 52.83, 52.78, 51.70, 51.67, 40.82, 37.16, 28.21.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{23}H_{26}NO_4$: 380.1857; found: 380.1858.

Methyl 1-(2-Fluorophenyl)-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ad)

Yield: 62.5 mg (85%); white solid; mp 165–166 °C; R_f = 0.55 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.84 (d, *J* = 8.2 Hz, 1 H), 7.37 (d, *J* = 7.4 Hz, 1 H), 7.07–6.93 (m, 3 H), 6.90 (td, *J* = 7.4, 1.0 Hz, 1 H), 6.82 (dd, *J* = 7.5, 6.6 Hz, 1 H), 6.77–6.69 (m, 1 H), 5.23 (d, *J* = 6.9 Hz, 1 H), 3.90 (d, *J* = 6.9 Hz, 1 H), 3.71 (s, 3 H), 1.56 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.2, 172.8, 144.1 ($J_{C–F}$ = 242.42 Hz), 133.6, 131.5 ($J_{C–F}$ = 25.31 Hz), 129.1, 128.0 ($J_{C–F}$ = 27.68 Hz), 127.8, 127.5, 125.6, 121.0 ($J_{C–F}$ = 4.75 Hz), 118.8, 111.4, 53.3, 53.2, 52.0, 52.0, 40.9, 36.4, 36.3, 32.2, 28.1.

^{19}F NMR (376 MHz, $CDCl_3$): δ = –113.28.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{23}FNO_3$: 368.1657; found: 368.1660.

Methyl 1-(2-Chlorophenyl)-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ae)

Yield: 53.7 mg (70%); white solid; mp 155–156 °C; R_f = 0.59 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.88 (d, *J* = 8.2 Hz, 1 H), 7.43 (d, *J* = 7.4 Hz, 1 H), 7.09–7.05 (m, 2 H), 7.02–6.94 (m, 3 H), 6.86 (t, *J* = 7.4 Hz, 1 H), 5.16 (d, *J* = 6.9 Hz, 1 H), 4.01 (d, *J* = 6.9 Hz, 1 H), 3.72 (s, 3 H), 1.57 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.1, 173.1, 145.2, 131.4, 130.7, 129.8, 129.2, 127.9, 127.6, 127.4, 123.4, 116.0, 53.1, 53.1, 51.8, 51.7, 40.9, 35.5, 35.5, 32.3, 28.1.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{23}ClNO_3$: 384.1361; found: 384.1364.

Methyl 1-(2-Bromophenyl)-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3af)

Yield: 61.7 mg (72%); white solid; mp 138–139 °C; R_f = 0.41 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.89 (d, *J* = 8.3 Hz, 1 H), 7.50–7.46 (m, 1 H), 7.28–7.23 (m, 1 H), 7.07 (dd, *J* = 7.7, 1.8 Hz, 1 H), 7.04–6.93 (m, 2 H), 6.93–6.82 (m, 2 H), 5.16 (d, *J* = 6.9 Hz, 1 H), 4.05 (d, *J* = 6.9 Hz, 1 H), 3.71 (s, 3 H), 1.57 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.1, 173.1, 144.9, 131.5, 129.8, 129.4, 129.4, 127.9, 127.5, 126.4, 119.5, 116.5, 53.2, 53.1, 51.5, 51.5, 40.9, 37.4, 37.3, 32.2, 28.1.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{23}BrNO_3$: 428.0856; found: 428.0861.

Methyl 1-(2-Nitrophenyl)-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ag)

Yield: 49.7 mg (63%); white solid; mp 221–223 °C; R_f = 0.25 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.23 (d, *J* = 2.0 Hz, 1 H), 7.95–7.85 (m, 2 H), 7.11–7.02 (m, 3 H), 6.99–6.92 (m, 2 H), 5.28 (d, *J* = 6.9 Hz, 1 H), 3.90 (d, *J* = 6.9 Hz, 1 H), 3.72 (s, 3 H), 1.57 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.1, 173.1, 145.2, 131.4, 130.7, 129.8, 129.2, 127.9, 127.6, 127.4, 123.4, 116.0, 53.1, 53.1, 51.8, 51.7, 40.9, 35.5, 35.5, 32.3, 28.1.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{23}N_2O_5$: 395.1602; found: 395.1605.

Methyl 1-(3-Chlorophenyl)-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ah)

Yield: 56.1 mg (73%); white solid; mp 124–125 °C; R_f = 0.53 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.83 (dd, *J* = 8.3, 0.9 Hz, 1 H), 7.39 (dd, *J* = 7.3, 1.5 Hz, 1 H), 7.05–6.93 (m, 5 H), 6.86–6.82 (m, 1 H), 5.20 (d, *J* = 7.0 Hz, 1 H), 3.83 (d, *J* = 7.0 Hz, 1 H), 3.70 (s, 3 H), 1.55 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 176.7, 173.1, 160.3, 157.8, 140.2, 131.6, 130.1, 129.6, 127.8, 118.8, 114.3, 112.1, 53.1, 53.0, 52.2, 52.1, 40.7, 36.2, 32.4, 28.2.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{23}ClNO_3$: 384.1361; found: 384.1362.

Methyl 1-(4-Methoxyphenyl)-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ai)

Yield: 72.9 mg (96%); white solid; mp 197–198 °C; R_f = 0.41 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.83 (d, *J* = 7.5 Hz, 1 H), 7.37 (dd, *J* = 7.3, 1.4 Hz, 1 H), 7.02–6.92 (m, 2 H), 6.86–6.80 (m, 4 H), 5.17 (d, *J* = 7.0 Hz, 1 H), 3.80 (d, *J* = 7.0 Hz, 1 H), 3.69 (s, 3 H), 2.15 (s, 3 H), 1.55 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.0, 173.7, 158.5, 144.2, 132.8, 128.4, 128.0, 124.9, 123.5, 121.8, 117.8, 113.2, 54.9, 53.0, 51.9, 40.8, 36.8, 31.7, 28.2.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{23}H_{26}NO_4$: 380.1857; found: 380.1961.

Methyl 2-Pivaloyl-1-(*p*-tolyl)-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3aj)

Yield: 69.1 mg (95%); white solid; mp 151–152 °C; R_f = 0.75 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.83 (d, *J* = 7.5 Hz, 1 H), 7.37 (dd, *J* = 7.3, 1.4 Hz, 1 H), 7.02–6.92 (m, 2 H), 6.86–6.80 (m, 4 H), 5.17 (d, *J* = 7.0 Hz, 1 H), 3.80 (d, *J* = 7.0 Hz, 1 H), 3.69 (s, 3 H), 2.15 (s, 3 H), 1.55 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.0, 173.6, 144.2, 136.9, 131.5, 128.5, 127.9, 126.8, 125.0, 123.5, 117.8, 53.0, 51.9, 40.8, 36.7, 32.0, 28.2, 21.1.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{23}H_{26}NO_3$: 364.1907; found: 364.1910.

Methyl 1-(4-Fluorophenyl)-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ak)

Yield: 61.7 mg (84%); white solid; mp 210–211 °C; R_f = 0.61 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.15 (d, *J* = 1.4 Hz, 1 H), 7.44 (d, *J* = 7.8 Hz, 1 H), 7.24 (dd, *J* = 7.8, 1.4 Hz, 1 H), 7.10–7.02 (m, 3 H), 6.93 (dd, *J* = 7.9, 1.6 Hz, 2 H), 5.25 (d, *J* = 6.9 Hz, 1 H), 3.86 (d, *J* = 6.8 Hz, 1 H), 3.71 (s, 3 H), 1.54 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 176.9, 173.1, 143.2 ($J_{C–F}$ = 242.42 Hz), 131.6, 130.8, 130.6, 129.5 ($J_{C–F}$ = 54.32 Hz), 127.9, 127.8, 127.5 ($J_{C–F}$ = 3.52 Hz), 119.1 ($J_{C–F}$ = 2.73 Hz), 115.9, 53.1, 53.1, 52.0, 51.9, 40.8, 36.1, 36.0, 32.2, 28.2.

^{19}F NMR (376 MHz, $CDCl_3$): δ = –109.89.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{23}FNO_3$: 368.1657; found: 368.1660.

Methyl 1-(4-Chlorophenyl)-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3al)

Yield: 72.9 mg (95%); white solid; mp 154–155 °C; R_f = 0.48 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.76 (d, *J* = 8.2 Hz, 1 H), 7.09–7.01 (m, 6 H), 6.84 (t, *J* = 8.1 Hz, 1 H), 5.19 (d, *J* = 7.0 Hz, 1 H), 3.89 (d, *J* = 7.0 Hz, 1 H), 3.71 (s, 3 H), 1.56 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.2, 172.8, 144.1, 133.6, 131.5, 129.1, 128.0, 127.8, 127.5, 125.6, 121.0, 118.8, 111.4, 53.3, 53.2, 52.0, 52.0, 40.9, 36.4, 36.3, 32.2, 28.1.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{23}ClNO_3$: 384.1356; found: 384.1356.

Methyl 1-(4-Bromophenyl)-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3am)

Yield: 80.5 mg (94%); white solid; mp 187–188 °C; R_f = 0.47 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.84 (d, *J* = 8.1 Hz, 1 H), 7.38–7.33 (m, 1 H), 7.18–7.14 (m, 2 H), 7.05–7.01 (m, 1 H), 6.99–6.96 (m, 1 H), 6.85–6.80 (m, 2 H), 5.19 (d, *J* = 7.0 Hz, 1 H), 3.82 (d, *J* = 7.0 Hz, 1 H), 3.69 (s, 3 H), 1.55 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 176.9, 172.8, 144.0, 133.3, 132.2, 131.0, 129.4, 129.1, 128.3, 128.0, 124.9, 123.7, 121.6, 118.0, 53.0, 51.9, 40.8, 36.6, 31.7, 28.2.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{23}BrNO_3$: 428.0856; found: 428.0861.

Methyl 1-(2,4-Dimethoxyphenyl)-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3an)

Yield: 80.3 mg (98%); white solid; mp 136–137 °C; R_f = 0.18 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.84 (d, *J* = 8.0 Hz, 1 H), 7.38–7.34 (m, 1 H), 6.60–6.54 (m, 2 H), 6.60–6.54 (m, 2 H), 6.39 (d, *J* = 1.5 Hz, 1 H), 5.18 (d, *J* = 7.0 Hz, 1 H), 3.80 (d, *J* = 7.0 Hz, 1 H), 3.73 (s, 3 H), 3.71 (s, 3 H), 3.63 (s, 3 H), 1.55 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 176.93, 173.57, 148.01, 147.98, 144.28, 128.48, 128.10, 124.79, 124.36, 123.47, 122.10, 117.93, 115.18, 110.33.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{24}H_{28}NO_5$: 410.1962; found: 410.1963.

Methyl 1-(Naphthalen-1-yl)-2-pivaloyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ao)

Yield: 78.3 mg (88%); white solid; mp 195–196 °C; R_f = 0.47 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.01 (d, *J* = 8.6 Hz, 1 H), 7.79 (d, *J* = 8.3 Hz, 1 H), 7.64 (d, *J* = 8.1 Hz, 1 H), 7.54 (d, *J* = 8.1 Hz, 1 H), 7.50–7.44 (m, 1 H), 7.36 (dd, *J* = 11.0, 4.0 Hz, 1 H), 7.23 (dd, *J* = 7.1, 1.2 Hz, 1 H), 7.19–7.14 (m, 1 H), 6.95 (d, *J* = 7.4 Hz, 1 H), 6.76 (dd, *J* = 11.5, 4.3 Hz, 1 H), 6.52–6.46 (m, 1 H), 5.28 (d, *J* = 7.0 Hz, 1 H), 4.17 (d, *J* = 7.0 Hz, 1 H), 3.63 (s, 3 H), 1.63 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 176.9, 173.8, 144.0, 133.5, 132.7, 128.7, 128.6, 128.4, 127.7, 127.2, 126.6, 125.9, 125.3, 125.3, 124.5, 124.1, 122.8, 117.2, 53.0, 52.0, 40.9, 38.1, 29.6, 28.3.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{26}H_{26}NO_3$: 400.1907; found: 400.1907.

Methyl 2-Pivaloyl-1-(thiophen-2-yl)-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3ap)

Yield: 61.1 mg (86%); white solid; mp 140–141 °C; R_f = 0.50 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.94 (d, *J* = 8.2 Hz, 1 H), 7.39–7.34 (m, 1 H), 7.10–6.96 (m, 3 H), 6.65 (dd, *J* = 5.2, 3.6 Hz, 1 H), 6.55 (dd, *J* = 3.6, 1.2 Hz, 1 H), 5.22 (d, *J* = 7.0 Hz, 1 H), 3.94 (d, *J* = 7.0 Hz, 1 H), 3.74 (s, 3 H), 1.53 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.0, 172.7, 144.7, 131.7, 130.8, 128.3, 127.8, 126.0, 125.7, 125.1, 123.7, 117.8, 53.3, 53.2, 40.8, 39.0, 28.1, 27.5.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{20}H_{22}NO_3S$: 356.1315; found: 356.1319.

1-[1-Acetyl-1-phenyl-1,6b-dihydrocyclopropa[*b*]indol-2(1a*H*)-yl]-2,2-dimethylpropan-1-one (3aq)

Yield: 48.6 mg (73%); white solid; mp 155–156 °C; R_f = 0.65 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.84–7.78 (m, 1 H), 7.37 (dd, *J* = 7.2, 1.5 Hz, 1 H), 7.06–6.99 (m, 3 H), 6.99–6.91 (m, 4 H), 5.20 (d, *J* = 7.0 Hz, 1 H), 3.83 (d, *J* = 7.0 Hz, 1 H), 3.69 (s, 3 H), 1.56 (s, *J* = 2.8 Hz, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.0, 173.4, 144.1, 131.8, 129.9, 128.4, 127.9, 127.6, 127.3, 125.0, 123.5, 117.8, 53.0, 51.8, 40.8, 36.7, 28.2.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{22}H_{24}NO_2$: 333.1729; found: 333.1731.

Methyl 1-Phenyl-2-(pyrimidin-2-yl)-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3aa-1)

Yield: 45.3 mg (66%); white solid; mp 210–211 °C; R_f = 0.36 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.55 (d, *J* = 4.7 Hz, 2 H), 7.97 (d, *J* = 8.2 Hz, 1 H), 7.44 (d, *J* = 7.2 Hz, 1 H), 7.06–7.00 (m, 1 H), 6.99–6.94 (m, 1 H), 6.90 (t, *J* = 7.4 Hz, 3 H), 6.86–6.79 (m, 3 H), 5.40 (d, *J* = 6.8 Hz, 1 H), 3.85 (d, *J* = 6.8 Hz, 1 H), 3.69 (s, 3 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 174.1, 159.4, 157.7, 142.8, 132.3, 130.6, 129.5, 127.6, 127.4, 127.0, 125.3, 121.7, 115.5, 113.1, 52.7, 51.8, 35.3, 32.0.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{21}H_{18}N_3O_2$: 344.1394; found: 344.1396.

Methyl 1-Phenyl-2-tosyl-1,1a,2,6b-tetrahydrocyclopropa[*b*]indole-1-carboxylate (3aa-2)

Yield: 55.4 mg (66%); white solid; mp 210–211 °C; R_f = 0.30 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.67 (d, *J* = 8.3 Hz, 2 H), 7.32–7.28 (m, 1 H), 7.20 (dd, *J* = 7.7, 5.2 Hz, 3 H), 7.12–7.03 (m, 5 H), 6.97–6.93 (m, 1 H), 6.92–6.89 (m, 1 H), 4.93 (d, *J* = 6.6 Hz, 1 H), 3.64 (s, 3 H), 3.60 (d, *J* = 6.6 Hz, 1 H), 2.35 (s, 3 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 173.2, 144.4, 141.3, 135.4, 132.4, 129.9, 129.6, 129.5, 127.8, 127.6, 127.3, 126.9, 125.6, 123.6, 114.3, 53.1, 52.9, 35.2, 30.7, 21.6.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{24}H_{22}NO_4S$: 420.1264; found: 420.1267.

2-*tert*-Butyl-1-methyl-1-phenyl-1,6b-dihydrocyclopropa[*b*]indole-1,2(1a*H*)-dicarboxylate (3aa-3)

Yield: 47.5 mg (65%); white solid; mp 210–211 °C; R_f = 0.55 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$) two rotamers (dr = 1:1), δ = 7.4–7.32 (m, 2 H_a + 2 H_b), 7.06–7.01 (m, 3 H_a + 3 H_b), 7.00–6.92 (m, 3 H_a + 3 H_b), 6.91–6.82 (m, 1 H_a + 1 H_b), 5.00–4.90 (d, *J* = 6.44 Hz, 1 H_a), 4.89–4.79 (d, *J* = 6.44 Hz, 1 H_b), 3.76–3.68 (m, 1 H_a + 1 H_b), 3.66 (s, 3 H_a), 3.64 (s, 3 H_b), 1.64 (s, 9 H_a), 1.57 (s, 9 H_b).

^{13}C NMR (101 MHz, $CDCl_3$) two rotamers (dr = 1:1), δ = 173.6, 173.4, 152.9, 151.7, 142.4, 141.3, 132.3, 132.1, 130.3, 129.2, 128.8, 128.5, 128.0, 127.9, 127.6, 127.3, 125.6, 125.1, 122.4, 122.3, 114.6, 114.4, 82.6, 81.8, 52.7, 52.2, 50.7, 50.6 35.5, 34.6, 32.1, 31.8, 28.5, 28.3.

HRMS (ESI): *m/z* [M + Na]$^+$ calcd for $C_{22}H_{23}NO_4Na$: 388.1519; found: 388.1520.

Methyl 6-Phenyl-2-pivaloyl-2-azabicyclo[3.1.0]hex-3-ene-6-carboxylate (4aa)

Yield: 29.9 mg (45%); white solid; mp 122–123 °C; R_f = 0.50 (PE–EtOAc, 10:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.25–7.17 (m, 3 H), 7.08–7.04 (m, 2 H), 6.26 (s, 1 H), 5.31 (dd, *J* = 3.8, 2.9 Hz, 1 H), 4.91 (d, *J* = 6.7 Hz, 1 H), 3.62 (s, 3 H), 3.24 (dd, *J* = 6.6, 2.5 Hz, 1 H), 1.10 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 175.5, 173.7, 132.8, 130.9, 130.1, 127.8, 127.3, 109.9, 52.6, 50.3, 39.1, 31.0, 27.6.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{18}H_{22}NO_3$: 300.1594; found: 300.1598.

Dimethyl-3,7-Diphenyl-5-pivaloyl-5-azatricyclo[4.1.0.02,4]heptane-3,7-dicarboxylate (4ab)

Yield: 40.3 mg (45%); white solid; mp 212–213 °C; R_f = 0.43 (PE–EtOAc, 5:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.41–7.27 (m, 9 H), 7.25–7.19 (m, 2 H), 3.57 (s, 3 H), 3.49 (s, 3 H), 3.38 (d, *J* = 6.5 Hz, 1 H), 3.30 (d, *J* = 6.4 Hz, 1 H), 2.79 (d, *J* = 6.6 Hz, 1 H), 2.44 (d, *J* = 6.4 Hz, 1 H), 1.20 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.7, 171.8, 171.7, 132.0, 131.4, 131.3, 130.8, 128.7, 128.6, 128.0, 127.8, 52.9, 52.6, 50.3, 50.2, 39.2, 38.6, 37.3, 34.3, 30.6, 27.9.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{27}H_{30}NO_5$: 448.2119; found: 448.2123.

2-(1*H*-Indol-3-yl)-2-phenylacetic Acid (5a)

Yield: 30.2 mg (60%); brown solid; mp 310–312 °C; R_f = 0.43 (DCM–EtOAc, 2:1).

^{1}H NMR (400 MHz, DMSO): δ = 12.57 (br, 1 H), 10.99 (s, 1 H), 7.42–7.34 (m, 4 H), 7.32–7.27 (m, 2 H), 7.25–7.20 (m, 2 H), 7.08–7.03 (m, 1 H), 6.95–6.90 (m, 1 H), 5.18 (s, 1 H).

^{13}C NMR (101 MHz, DMSO): δ = 173.9, 139.7, 136.2, 128.3, 128.1, 126.7, 126.3, 123.5, 121.1, 118.6, 118.5, 112.7, 111.5, 48.4.

HRMS (ESI): *m/z* [M + H]$^+$ calcd for $C_{16}H_{14}NO_2$: 252.1019; found: 252.1017.

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Supporting Information

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References

(1) (a) Ebner, C.; Carreira, E. M. *Chem. Rev.* **2017**, *117*, 1165. (b) Jin, S.; Gong, J.; Qin, Y. *Angew. Chem. Int. Ed.* **2015**, *54*, 2228. (c) Kirillova, M. S.; Muratore, M. E.; Dorel, R.; Echavarren, A. M. *J. Am. Chem. Soc.* **2016**, *138*, 3671. (d) Leng, L.; Zhou, X.; Liao, Q.; Wang, F.; Song, H.; Zhang, D.; Liu, X. Y.; Qin, Y. *Angew. Chem. Int. Ed.* **2017**, *56*, 3703. (e) Yang, J.; Song, H.; Xiao, X.; Wang, J.; Qin, Y. *Org. Lett.* **2006**, *8*, 2187. (f) Zhang, D.; Song, H.; Qin, Y. *Acc. Chem. Res.* **2011**, *44*, 447.

(2) (a) Ferrer, C.; Escribano-Cuesta, A.; Echavarren, A. M. *Tetrahedron* **2009**, *65*, 9015. (b) Kam, T.-S.; Lim, K.-H.; Yoganathan, K.; Hayashi, M.; Komiyama, K. *Tetrahedron* **2004**, *60*, 10739.

(3) (a) Huang, H. X.; Jin, S. J.; Gong, J.; Zhang, D.; Song, H.; Qin, Y. *Chem. Eur. J.* **2015**, *21*, 13284. (b) Shen, L.; Zhang, M.; Wu, Y.; Qin, Y. *Angew. Chem. Int. Ed.* **2008**, *47*, 3618. (c) Gagnon, D.; Spino, C. *J. Org. Chem.* **2009**, *74*, 6035.

(4) For selective examples of cyclopropanation of indoles with diazo compounds, see: (a) Davies, H. L. M.; Hedley, S. J. *Chem. Soc. Rev.* **2007**, *36*, 1109. (b) Zhang, B.; Wee, A. G. H. *Chem. Commun.* **2008**, *39*, 4837. (c) Fraile, J. M.; Le Jeune, K.; Mayoral, J. A.; Ravasio, N.; Zaccheria, F. *Org. Biomol. Chem.* **2013**, *11*, 4327. (d) Liu, K.; Xu, G.; Sun, J. *Chem. Sci.* **2018**, *9*, 634. (e) Zhang, B.; Wee, A. G. *Org. Biomol. Chem.* **2012**, *10*, 4597.

(5) For selective examples of cyclopropanation of indoles with *N*-tosylhydrazones, see: Reddy, A. R.; Hao, F.; Wu, K.; Zhou, C. Y.; Che, C. M. *Angew. Chem. Int. Ed.* **2016**, *55*, 1810.

(6) Xu, H.; Li, Y. P.; Cai, Y.; Wang, G. P.; Zhu, S. F.; Zhou, Q. L. *J. Am. Chem. Soc.* **2017**, *139*, 7697.

(7) Pirovano, V.; Brambilla, E.; Tseberlidis, G. *Org. Lett.* **2018**, *20*, 405.

(8) Chen, W.; Ji, D.-S.; Luo, Y.-C.; Wang, Z.-Y.; Xu, P.-F. *Org. Chem. Front.* **2018**, *5*, 1768.

(9) For selective visible-light-induced functionalization, see: (a) Liang, Y.; Zhang, X.; MacMillan, D. W. C. *Nature* **2018**, *559*, 83. (b) Le, C.; Chen, T. Q.; Liang, T.; Zhang, P.; MacMillan, D. W. C. *Science* **2018**, *360*, 1010. (c) Gandeepan, P.; Mo, J.; Ackermann, L. *Chem. Commun.* **2017**, *53*, 5906. (d) Hari, D. P.; Schroll, P.; Konig, B. *J. Am. Chem. Soc.* **2012**, *134*, 2958. (e) Mateos, J.; Cherubini-Celli, A.; Carofiglio, T.; Bonchio, M.; Marino, N.; Companyo, X.; Dell'Amico, L. *Chem. Commun.* **2018**, *54*, 6820. (f) Pagire, S. K.; Hossain, A.; Traub, L.; Kerres, S.; Reiser, O. *Chem. Commun.* **2017**, *53*, 12072. (g) Shen, Z. C.; Yang, P.; Tang, Y. *J. Org. Chem.* **2016**, *81*, 309. (h) Tang, X.; Studer, A. *Angew. Chem. Int. Ed.* **2018**, *57*, 814. (i) Xiao, T.; Li, L.; Lin, G.; Mao, Z. W.; Zhou, L. *Org. Lett.* **2014**, *16*, 4232. (j) Yang, J. C.; Zhang, J. Y.; Zhang, J. J.; Duan, X. H.; Guo, L. N. *J. Org. Chem.* **2018**, *83*, 1598. (k) Zhao, Y. N.; Luo, Y. C.; Wang, Z. Y.; Xu, P. F. *Chem. Commun.* **2018**, *54*, 3993. (l) Ye, C.; Zhang, Y.; Ding, A.; Hu, Y.; Guo, H. *Sci. Rep.* **2018**, *8*, 2205. (m) Li, H.; Jin, R.; Li, Y.; Ding, A.; Hao, X.; Guo, H. *Sci. Rep.* **2017**, *7*, 16559. (n) Zhu, M.; Zhou, K.; Zhang, X.; You, S.-L. *Org. Lett.* **2018**, *20*, 4379. (o) Cheng, Y.-Z.; Zhou, K.; Li, L.-A.-C.; Zhang, X.; You, S.-L. *Chem. Eur. J.* **2018**, *24*, 12519. (p) Liu, Y.-Y.; Yu, X.-Y.; Chen, J.-R.; Qiao, M.-M.; Qi, X.; Shi, D.-Q.; Xiao, W.-J. *Angew. Chem. Int. Ed.* **2017**, *56*, 9527. (q) Xia, X.-D.; Ren, Y.-L.; Chen, J.-R.; Yu, X.-L.; Lu, L.-Q.; Zou, Y.-Q.; Wan, J.; Xiao, W.-J. *Chem. Asian J.* **2014**, *9*, 1.

(10) (a) Strieth-Kalthoff, F.; James, M. J.; Teders, M.; Pitzer, L.; Glorius, F. *Chem. Soc. Rev.* **2018**, 47, 7190. (b) Xuan, J.; Xiao, W. J. *Angew. Chem. Int. Ed.* **2012**, *51*, 6828. (c) Romero, N. A.; Nicewicz, D. A. *Chem. Rev.* **2016**, *116*, 10075. (d) Prier, C. K.; Rankic, D. A.; MacMillan, D. W. C. *Chem. Rev.* **2013**, *113*, 5322.

(11) For selective metal- and photocatalyst-free functionalization see: (a) Jurberg, I. D.; Davies, H. M. L. *Chem. Sci.* **2018**, *9*, 5112. (b) Li, J.; Zhang, P.; Jiang, M.; Yang, H.; Zhao, Y.; Fu, H. *Org. Lett.* **2017**, *19*, 1994. (c) Xiao, T.; Mei, M.; He, Y.; Zhou, L. *Chem. Commun.* **2018**, *54*, 8865. (d) Ni, K.; Meng, L. G.; Wang, K.; Wang, L. *Org. Lett.* **2018**, *20*, 2245. (e) Li, X.; Gu, X.; Li, L.; Li, P. *ACS Catal.* **2014**, *4*, 1897.

(12) CCDC 1862501 contains the supplementary crystallographic data for this paper. The data can be obtained free of charge from The Cambridge Crystallographic Centre via www.ccdc.cam.ac.uk/getstructures.

(13) (a) Zhu, Z.; Bally, T.; Stracener, L. L.; McMahon, R. J. *J. Am. Chem. Soc.* **1999**, *121*, 2863. (b) Wang, Y.; Yuzawa, T.; Hamaguchi, H.-O.; Toscano, J. P. *J. Am. Chem. Soc.* **1999**, *121*, 2875. (c) Li, Y. Z.; Schuster, G. B. *J. Org. Chem.* **1987**, *52*, 4460.

(14) Stuart, D. R.; Villemure, E.; Fagnou, K. *J. Am. Chem. Soc.* **2007**, *129*, 12072.

(15) (a) Keipour, H.; Jalba, A.; Delage-Laurin, A.; Ollevier, T. *J. Org. Chem.* **2017**, *82*, 3000. (b) Song, Z.; Wu, Y.; Xin, T.; Jin, J.; Wen, X.; Sun, H.; Xu, Q. L. *Chem. Commun.* **2016**, *52*, 6079.