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A palladium-catalyzed tandem cyclization-cross-coupling reaction using indolylborate as a transfer agent

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Abstract—Investigation of the palladium-catalyzed tandem cyclization-cross-coupling reaction using indolylborate (**2**) as a transfer agent has been carried out. Furthermore, the cross-coupling reaction performed under carbon monoxide led to the generation of indolyl ketones.
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1. Introduction

Metal-catalyzed cross-coupling reactions have now become a quite significant synthetic tool for the carbon–carbon bond formation, and have furnished an enormous variety of fascinating transformations.[1] Within this research, the search for palladium-catalyzed tandem Heck-type carbocyclization-cross-coupling reactions has provided a vast development that complex entities can be built up in a one-pot protocol,[2] in which various organometallic reagents such as zinc, tin, and magnesium compounds were adapted as transfer agents to take advantage of their high reactivity. The Suzuki cross-coupling protocol has now emerged as the method of choice in various chemical transformations,[3] for which phenylboronic acid is ranked among the premier transfer agents, whereas the use of organoboron compounds in the tandem process is of limited significance.[4] Notably, tetravalent organoboron compounds (ate complexes) have proven to offer less practical advantages over other agents.[5]

In connection with our project to elucidate indolylborate (**2**) as a potential synthetic intermediate,[6] we have previously disclosed that **2** is highly effective, though nevertheless an ate complex, in the palladium-catalyzed cross-coupling process.[7] By taking advantage of the attractive features of **2** in the cross-coupling reaction, we have interested in whether **2** might also be valid as a transfer agent in the palladium-catalyzed tandem cyclization-cross-coupling process, and herein, we report the detailed results of our investigation.[8]

Keywords: Indolylborate; Cascade reaction; Cross-coupling reaction; Carbonylation; Palladium catalyst.
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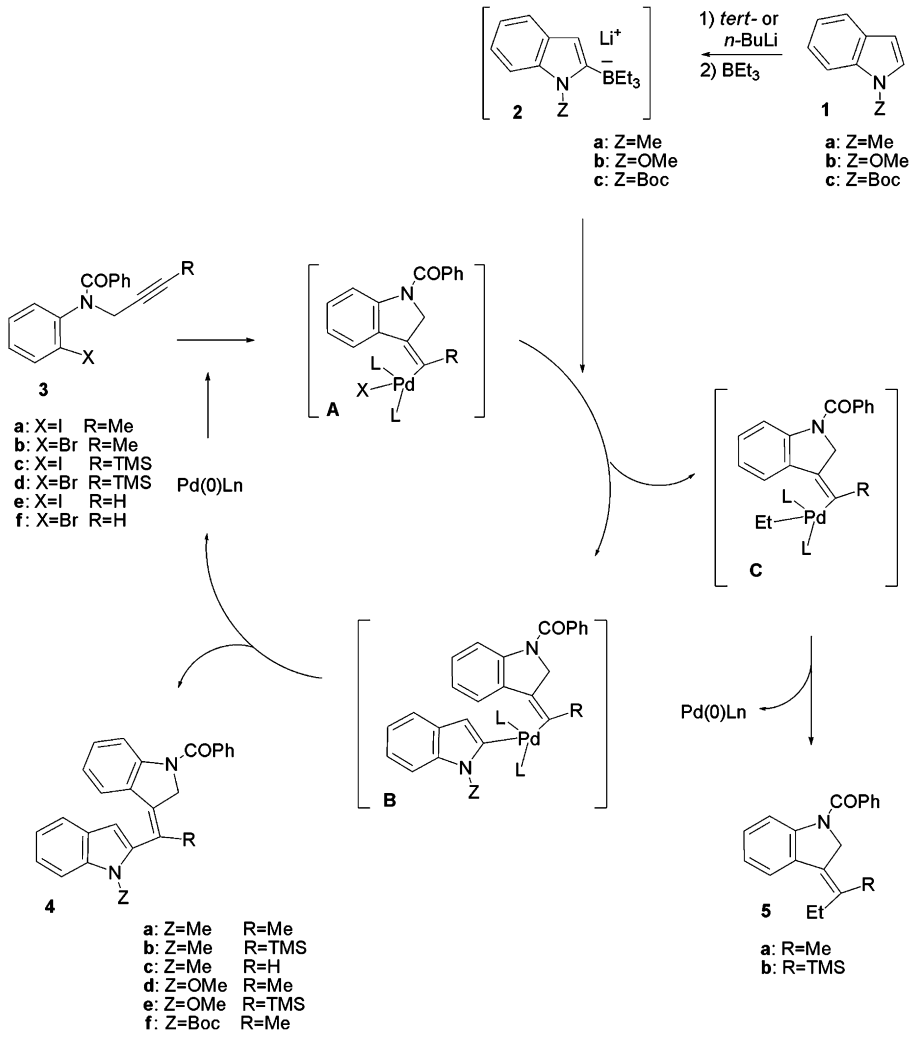
2. Results and discussion

At first, we have set about our study by reacting **2**, generated from the corresponding indole (**1**) and triethylborane in situ,[9] with **3** in the presence of a catalytic amount of palladium complex (5 mol %). The following common mechanistic scheme might account for the present reaction (Scheme 1); (1) the palladium-catalyzed Heck-type cyclization of **3**, (2) the transmetalation between complex (**A**) and **2** possibly involving transfer of the indole ring and/or the Et group, and (3) the subsequent reductive elimination. The implementation of the present protocol requires a potent transfer of the indole ring of **2** (**A**→**B**) to produce **4**, while competitive transfer of the ethyl group of **2** (**A**→**C**) should account for the formation of **5**.

On treating **2a** with 1 and 2 equiv of **3a** in the presence of $Pd(OAc)_2$, **4a** was obtained in 60 and 53% yields, respectively, along with substantial amounts of **5a** as a byproduct. Eventually, the successful reaction of **2a** with **3a** could be achieved using an excess amount of **2a** (ca. 2 equiv) in the presence of $Pd(OAc)_2$ in THF at 60 °C, which proceeded to completion within 30 min, allowing the isolation of **4a** in 78% yield along with trace amounts of **5a** (Table 1). On the other hand, marked retardation in the yield of **4a** and the appreciable appearance of **5a** were observed in the reaction with PPh_3. Under the same conditions, treatment of **2a** with bromide (**3b**) resulted in a lower yield of **4a** together with substantial amounts of **5a**.

The (*E*)-configuration in **4a** was firmly established based on NOE experiments, in which irradiation of the H2′-proton at δ 4.82 gave NOE enhancement of the methyl group at δ 2.04 (Chart 1).



Scheme 1.

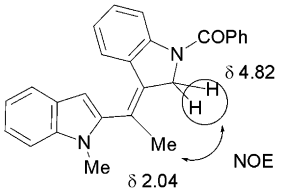


Chart 1.

It is possible that the increased steric bulkiness on the Pd in **A** (L=PPh_3) or the decrease in the positive charge on the Pd in **A** (X=Br)[10] might hamper the coordination–transmetalation step, thus allowing enough time for side reactions and resulting in the formation of **4a** and **5a** with the observed selectivity.

A clear steric effect was observed during the reaction of *N*-Boc-indolylborate (**2c**). The reaction of **2c** with **3a** became sluggish, giving **4f** in 23% yield along with **5a** (20%) and unreacted **3a** (18%) after heating for 2 h. With **3c** having a bulky TMS group on the alkyne terminus, the reaction of **2c** failed to isolate cross-coupling products, resulting in substantial amounts of **3c** and other unidentified compounds.

The reaction of **2a** with **3e** and **3f** was messy, allowing the isolation of **4c** only in a low yield. This is likely due to the lower stability of complex (**A**) (R=H) during the transmetalation step.

A closely related reaction outcome could be observed on the reaction of **2** with **6** (Table 2). When the reaction was performed in the presence of PPh_3, a decrease in the yield of **7** and the appearance of **8** were observed.

Subjection of iodides (**9**)[11] to the reaction with **2a** under the same conditions also afforded cross-coupling products (**10**) in good yields (Scheme 2).

To explore the advantage of this reaction, we next investigated the reaction of **2** with **11** having an olefin moiety under the same conditions. The initially attempted reaction of **2a** with **11** was messy, and resulted in the isolation of **12** and **13** in low yields (Table 3).

Due to the possible presence of multiple paths acting simultaneously in the decomposition of the σ-alkyl palladium complex (**D**),[12] there is no clear account for the formation of **12**. One possibility suggests that the homolytic cleavage

Table 1. Tandem cyclization-cross-coupling reaction of **2** with **3**[a]

2	3	PdLn	Time (h)	Yield (%)[b] of **4**	Yield (%)[b] of 5
2a	**3a**	$Pd(OAc)_2$	1	53 (**4a**)[c]	13 (**5a**)[c]
2a	**3a**	$Pd(OAc)_2$	1	60 (**4a**)[d]	10 (**5a**)[d]
2a	**3a**	$Pd(OAc)_2$	0.5	78 (**4a**)	—
2a	**3a**	$Pd(OAc)_2$+2PPh_3	1	37 (**4a**)	30 (**5a**)
2a	**3a**	$Pd_2(dba)_3CHCl_3$	0.5	75 (**4a**)	—
2a	**3a**	$Pd_2(dba)_3CHCl_3$+4PPh_3	1	34 (**4a**)	31 (**5a**)
2a	**3a**	$PdCl_2(CH_3CN)_2$	0.5	75 (**4a**)	—
2a	**3b**	$Pd(OAc)_2$	1	53 (**4a**)	15 (**5a**)
2a	**3b**	$Pd(OAc)_2$+2PPh_3	1	35 (**4a**)	23 (**5a**)
2a	**3b**	$Pd_2(dba)_3CHCl_3$	1	50 (**4a**)	20 (**5a**)
2a	**3b**	$Pd_2(dba)_3CHCl_3$+4PPh_3	2	29 (**4a**)	35 (**5a**)
2a	**3b**	$PdCl_2(CH_3CN)_2$	1	53 (**4a**)	15 (**5a**)
2a	**3b**	$PdCl_2(CH_3CN)_2$+2PPh_3	2	35 (**4a**)	25 (**5a**)
2a	**3c**	$Pd(OAc)_2$	0.5	71 (**4b**)	—
2a	**3c**	$PdCl_2(CH_3CN)_2$	0.5	71 (**4b**)	—
2a	**3c**	$Pd_2(dba)_3CHCl_3$	0.5	72 (**4b**)	—
2a	**3d**	$Pd(OAc)_2$	1	55 (**4b**)	15 (**5b**)
2a	**3d**	$PdCl_2(CH_3CN)_2$	1	51 (**4b**)	15 (**5b**)
2a	**3e**	$Pd(OAc)_2$	0.5	34 (**4c**)	—
2a	**3e**	$Pd(OAc)_2$+2PPh_3	1	24 (**4c**)	—
2a	**3e**	$Pd_2(dba)_3CHCl_3$	0.5	29 (**4c**)	—
2a	**3e**	$Pd_2(dba)_3CHCl_3$+4PPh_3	1	12 (**4c**)	—
2a	**3f**	$Pd(OAc)_2$	1	27 (**4c**)	—
2a	**3f**	$Pd(OAc)_2$+2PPh_3	1	18 (**4c**)	—
2b	**3a**	$Pd(OAc)_2$	1	70 (**4d**)	—
2b	**3c**	$Pd(OAc)_2$	1	65 (**4e**)	10 (**5b**)
2b	**3b**	$Pd(OAc)_2$	1	55 (**4d**)	10 (**5a**)
2b	**3d**	$Pd(OAc)_2$	1	43 (**4e**)	15 (**5b**)
2c	**3a**	$Pd(OAc)_2$	3	23 (**4f**)	20 (**5a**)
2c	**3c**	$Pd(OAc)_2$	3	—	—

[a] The reaction was carried out using indole (**1**) (2 equiv), **3** (1 equiv), and palladium complex (5 mol %) in THF under argon atmosphere at 60 °C.
[b] Yields based on **3**.
[c] Indole (**1a**) (1 equiv) and **3a** (2 equiv) and yield based on **1a**.
[d] Indole (**1a**) (1 equiv) and **3a** (1 equiv).

of the C–Pd bond, a commonly observable side reaction, is responsible for the generation of **12** (Scheme 3).[13] On the other hand, the nucleophilic attack of **2a** with a spontaneous intramolecular alkyl migration to complex (**D**) could have produced **13**.[14]

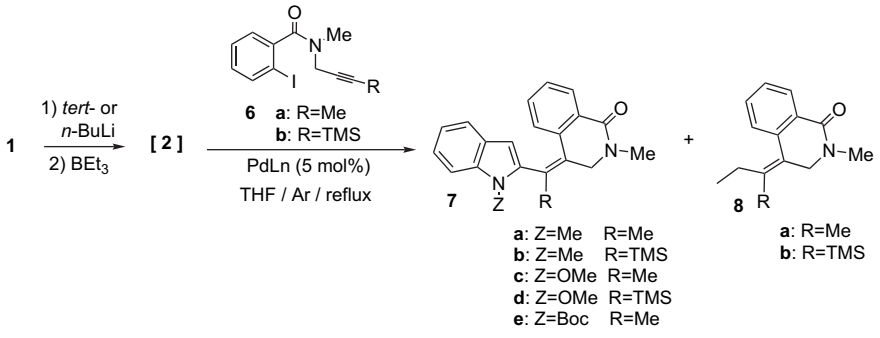
As several factors are generally known to enhance the stability of the σ-monoalkyl palladium complex, an increase in sterical hindrance was envisioned to exert an influence on the stability of σ-alkyl palladium intermediate, enabling the cross-coupling reaction to proceed.

Then, we next carried out the reaction using **14** under the same conditions (Table 4). As was expected, treatment of **2a**,**b** with **14** in the presence of $Pd(OAc)_2$ smoothly produced the cross-coupling product (**15**) in good yields. However, the presence of PPh_3 markedly altered the reaction outcome by resulting in a lower yield of **15** along with **16**.[15] A reason for this result is that the σ-alkyl palladium intermediate, generated from **14** by the way of carbopalladation, might possibly undergo homolytic cleavage of the C–Pd bond to give **16**.

Otherwise, treatment of **2a** with **17** allowed the isolation of two kinds of cross-coupling products **18a** and **19a**, in which a marked propensity for the yield of **18a** to exceed that of **19a** in the presence of PPh_3 was observed (Table 5). To our surprise, **19b** was exclusively obtained in the reaction of **2b** with **17**, and no additional products by way of the cascade reaction were isolated. The reaction of **2c** was also sluggish, giving rise to lower yield of **18b** together with the recovery of unreacted **17**.

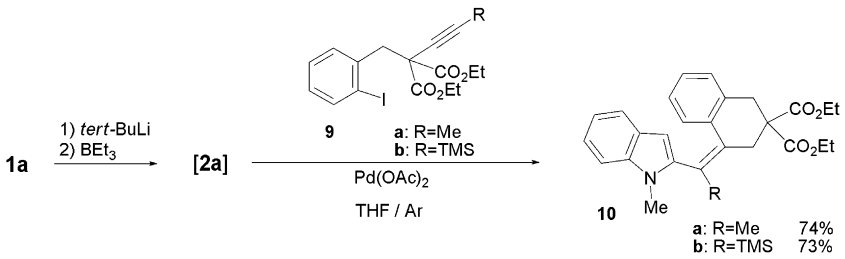
The conformational space of **14** is restricted by the presence of carbonyl sp^2 carbon involved in the tether, which enforces

Table 2. Tandem cyclization-cross-coupling reaction of **2** with **6**



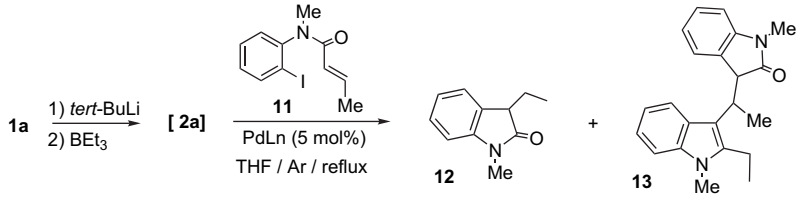
2	6	PdLn	Time (h)	Yield (%)[a] of **7**	Yield (%)[a] of **8**
2a	**6a**	$Pd(OAc)_2$	0.5	74 (**7a**)	—
2a	**6a**	$Pd(OAc)_2$+2PPh_3	0.5	55 (**7a**)	18 (**8a**)
2a	**6a**	$Pd_2(dba)_3CHCl_3$	0.5	71 (**7a**)	—
2a	**6a**	$PdCl_2(CH_3CN)_2$	0.5	70 (**7a**)	—
2a	**6a**	$PdCl_2(CH_3CN)_2$+2PPh_3	0.5	55 (**7a**)	10 (**8a**)
2a	**6b**	$Pd(OAc)_2$	0.5	73 (**7b**)	—
2a	**6b**	$PdCl_2(CH_3CN)_2$	0.5	63 (**7b**)	5 (**8b**)
2b	**6a**	$Pd(OAc)_2$	0.5	43 (**7c**)	—
2b	**6b**	$Pd(OAc)_2$	0.5	45 (**7d**)	—
2c	**6a**	$Pd(OAc)_2$	2	23 (**7e**)	15 (**8a**)[b]
2c	**6b**	$Pd(OAc)_2$	4	—	20 (**8b**)[c]

[a] Yields based on **6**.
[b] Recovery of **6a** (20%).
[c] Recovery of **6b** (30%) with unidentified products.



Scheme 2.

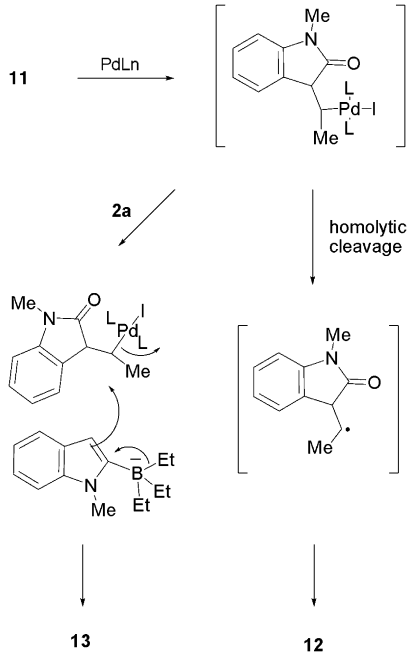
Table 3. Tandem cyclization-cross-coupling reaction of **2** with **11**



PdLn	Time (h)	Yield (%)[a] of **12**	Yield (%)[a] of **13**
$Pd(OAc)_2$	0.5	26	4
$Pd(OAc)_2$+2PPh_3	0.5	—[b]	—[b]
$Pd_2(dba)_3CHCl_3$	0.5	29	5
$PdCl_2(CH_3CN)_2$	0.5	24	2

[a] Yields based on **11**.
[b] Unidentified products.

Heck-type cyclization path. On the other hand, the lack of conformational restriction in **17** and free rotation around the C–N bond before the cyclization now made the direct cross-coupling process more favorable. Stabilization through the coordination of PPh_3 seems to be enough to minimize the transmetalation, so that the tandem cyclization-cross-coupling process might proceed.



Scheme 3.

Upon treatment of **2** with **20** under the same conditions, cross-coupling products **21** and **22** were similarly obtained, where the yield of **21** was greater than that of **22** in the absence of PPh_3 (Table 6).

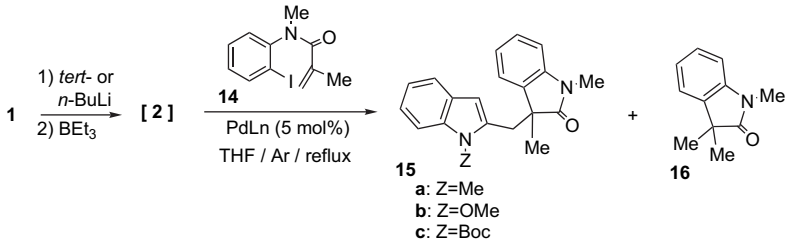
These results demonstrate that indolylborate (**2**) successfully serves as a transfer agent in the tandem cyclization-cross-coupling reaction. As we have previously reported the successful use of **2** for indolyl ketone synthesis by the way of the palladium-catalyzed carbonylative-cross-coupling reaction,[16] we then wondered if this protocol could be expanded to the cascade of cyclization–carbonylation-cross-coupling process.

When **2a** was simply treated with **14** in the presence of $PdCl_2(PPh_3)_2$ (5 mol %) in THF at 60 °C under carbon monoxide (10 atm), a 65% yield of ketone (**23a**) was obtained together with a small amount of **15a** (Table 7). The reaction using **2c** was less effective, producing ketone (**23b**) in 51% yield accompanied by the recovery of unreacted **14**.

Under the same conditions, the reaction of **2a** with **17** also proceeded to afford ketone (**24**) along with **18a** and **19a**. Unfortunately, on the treatment of **2a** with **20**, ketone (**25**) was obtained but in low a yield allowing the isolation of ketone (**26**) along with **22** (Scheme 4).

In summary, we have disclosed that **2**, which is a tetravalent organoboron compound, could offer practical advantages as a transfer agent in the palladium-catalyzed tandem cyclization-cross-coupling reaction. Moreover, it was also shown that **2** is effective for tandem cyclization–carbonylation-cross-coupling reactions, providing indolyl ketones.

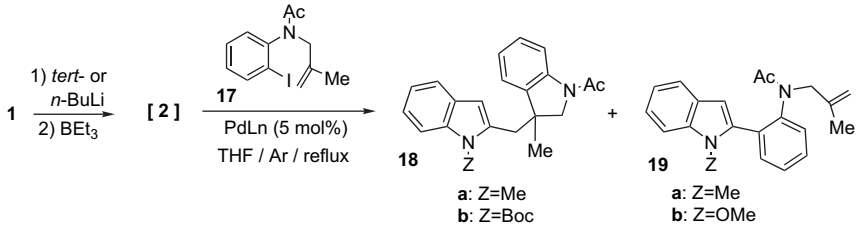
Table 4. Tandem cyclization-cross-coupling reaction of **2** with **14**



2	PdLn	Time (h)	Yield (%)[a] of **15**	Yield (%)[a] of **16**
2a	$Pd(OAc)_2$	0.5	75 (**15a**)	—
2a	$Pd(OAc)_2$+2PPh_3	0.5	53 (**15a**)	16
2b	$Pd(OAc)_2$	0.5	74 (**15b**)	—
2b	$PdCl_2(CH_3CN)_2$	0.5	70 (**15b**)	—
2c	$Pd(OAc)_2$	6	12 (**15c**)	30
2c	$Pd(OAc)_2$+2PPh_3	6	—	45

[a] Yields based on **14**.

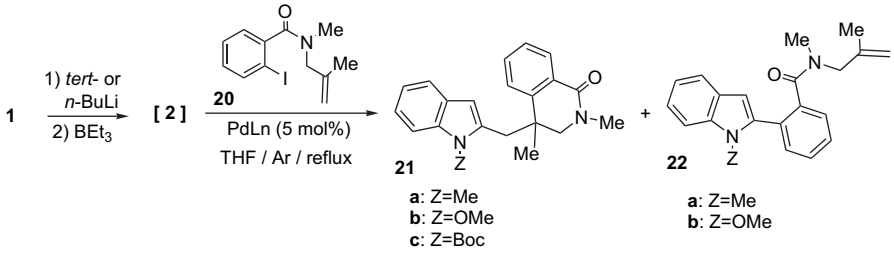
Table 5. Tandem cyclization-cross-coupling reaction of **2** with **17**



2	PdLn	Time (h)	Yield (%)[a] of **18**	Yield (%)[a] of **19**
2a	$Pd(OAc)_2$	0.5	13 (**18a**)	60 (**19a**)
2a	$Pd(OAc)_2$+2PPh_3	0.5	65 (**18a**)	10 (**19a**)
2a	$Pd_2(dba)_3CHCl_3$	0.5	12 (**18a**)	72 (**19a**)
2a	$PdCl_2(CH_3CN)_2$	0.5	10 (**18a**)	75 (**19a**)
2b	$Pd(OAc)_2$	0.5	—	80 (**19b**)
2b	$Pd(OAc)_2$+2PPh_3	0.5	—	70 (**19b**)
2c	$Pd(OAc)_2$	6	31 (**18b**)	—[b]
2c	$Pd(OAc)_2$+2PPh_3	6	51 (**18b**)	—[c]

[a] Yields based on **17**.
[b] Recovery of **17** (20%).
[c] Recovery of **17** (10%).

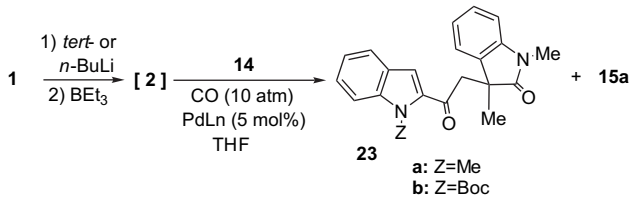
Table 6. Tandem cyclization-cross-coupling reaction of **2** with **20**



2	PdLn	Time (h)	Yield (%)[a] of **21**	Yield (%)[a] of **22**
2a	$Pd(OAc)_2$	1	26 (**21a**)	54 (**22a**)
2a	$Pd(OAc)_2$+2PPh_3	1	68 (**21a**)	5 (**22a**)
2b	$Pd(OAc)_2$	1	35 (**21b**)	20 (**22b**)
2b	$Pd(OAc)_2$+2PPh_3	1	63 (**21b**)	5 (**22b**)
2c	$Pd(OAc)_2$	5	32 (**21c**)	—[b]
2c	$Pd(OAc)_2$+2PPh_3	5	57 (**21c**)	—[c]

[a] Yields based on **20**.
[b] Recovery of **20** (20%) and unidentified products.
[c] Recovery of **20** (10%) and unidentified products.

Table 7. Tandem cyclization–carbonylation-cross-coupling reaction of **2** with **14**



2	PdLn	Yield (%)[a] of **23**	Yield (%)[a] of **15**
2a	$Pd(OAc)_2$	36 (**23a**)	31 (**15a**)
2a	$PdCl_2(Ph_3P)_2$	65 (**23a**)	5 (**15a**)
2c	$Pd(OAc)_2$	22 (**23b**)	—[b]
2c	$PdCl_2(Ph_3P)_2$	51 (**23b**)	—[c]

[a] Yields based on **14**.
[b] Recovery of **14** (30%).
[c] Recovery of **14** (10%).

3. Experimental

3.1. General

Melting points were recorded on a Yamato MP21 apparatus and are uncorrected. MS and high-resolution MS spectra were recorded on a Micromass AutoSpec 3100 mass spectrometer. IR spectra were measured on a Hitachi Model 270-30 spectrometer. The NMR experiments were performed with a JEOL JNM-LA300 or JNM-ECA500 spectrometer, and chemical shifts are expressed in parts per million (δ) with TMS as an internal reference. Medium pressure liquid chromatography (MPLC) was performed on silica gel (Silica Gel 60N, Kanto Chemical Co., Ltd.).

3.1.1. *N*-(2-Iodophenyl)-*N*-but-2-yn-1-ylbenzamide (3a). Treatment of **3e** (2 g, 5.5 mmol) with iodomethane (0.5 mL, 8 mmol) according to the literature[10] produced **3a** in 70% yield after separation by MPLC with hexane–AcOEt (10:1) as an eluent.

Colorless crystals. Mp 73–74 °C (hexane–AcOEt). IR ($CHCl_3$): 1642 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.76 (s, 3H), 4.07 (qd, 1H, J=2.0, 17.2 Hz), 5.09 (d, 1H, J=17.2 Hz), 6.90–6.93 (m, 1H), 7.12–7.25 (m, 5H), 7.38 (d, 2H, J=7.5 Hz), 7.80 (d, 1H, J=8.1 Hz). ^{13}C NMR ($CDCl_3$) δ: 3.7, 38.9, 73.7, 80.6, 99.9, 127.7, 128.3, 128.4, 128.5, 128.9, 129.4, 130.1, 132.1, 135.3, 140.0, 144.2, 170.3. MS *m/z*: 375 (M^+). Anal. Calcd for $C_{17}H_{14}INO$: C, 54.42; H, 3.76; N, 3.73. Found: C, 54.30; H, 3.87; N, 3.68.

3.1.2. *N*-(2-Bromophenyl)-*N*-but-2-yn-1-ylbenzamide (3b). Treatment of **3f** (2 g, 6.3 mmol) with iodomethane (0.5 mL, 8 mmol) according to the literature[10] produced **3b** in 71% yield after separation by MPLC with hexane–AcOEt (10:1) as an eluent.

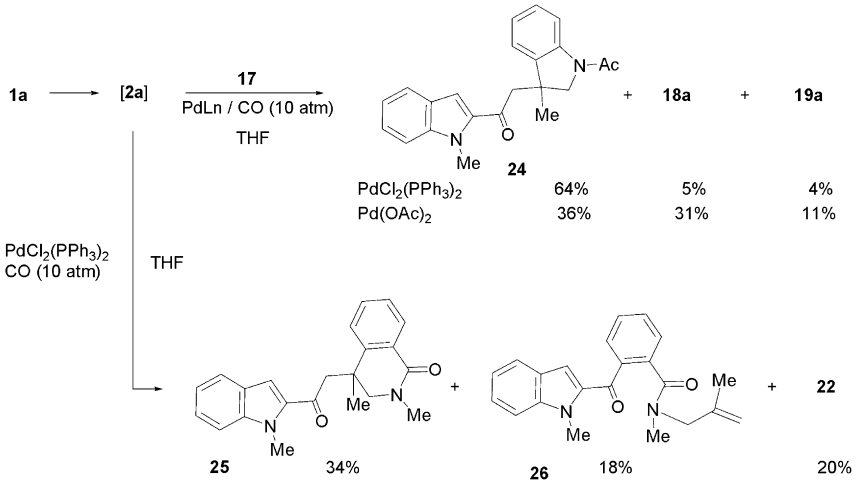
Viscous oil. IR ($CHCl_3$): 1646 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.76 (s, 3H), 4.09 (qd, 1H, J=2.0, 17.2 Hz), 5.09 (d, 1H, J=17.2 Hz), 7.05–7.25 (m, 6H), 7.36 (d, 2H, J=7.5 Hz), 7.54 (d, 1H, J=8.1 Hz). ^{13}C NMR ($CDCl_3$) δ: 3.69, 38.5, 73.8, 80.5, 123.2, 127.8, 128.1, 128.3, 129.4, 130.1, 132.5, 133.6, 135.3, 141.3, 170.5. HRMS *m/z* Calcd for $C_{17}H_{14}BrNO$: 327.0259 and 329.0238. Found: 327.0264 and 329.0225.

3.1.3. *N*-(2-Iodophenyl)-*N*-[3-(trimethylsilyl)prop-2-yn-1-yl]benzamide (3c). Treatment of **3e** (2 g, 5.5 mmol) with chlorotrimethylsilane (1 mL, 8 mmol) according to the literature[10] produced **3c** in 68% yield after separation by MPLC with hexane–AcOEt (10:1) as an eluent.

Viscous oil. IR ($CHCl_3$): 2340, 1660 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 0.09 (s, 9H), 4.16 (d, 1H, J=17.2 Hz), 5.20 (d, 1H, J=17.2 Hz), 6.91–6.94 (m, 1H), 7.10–7.28 (m, 5H), 7.38 (d, 2H, J=7.5 Hz), 7.78 (d, 1H, J=8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: 0.1, 39.0, 90.2, 100.2, 127.2, 128.5, 128.7, 129.6, 130.1, 132.5, 135.3, 139.9, 143.9, 170.1. HRMS *m/z* Calcd for $C_{19}H_{20}INOSi$: 433.0358. Found: 433.0348.

3.1.4. *N*-(2-Bromophenyl)-*N*-[3-(trimethylsilyl)prop-2-yn-1-yl]benzamide (3d). Treatment of **3f** (2 g, 6.3 mmol) with chlorotrimethylsilane (1 mL, 8 mmol) according to the literature[10] produced **3d** in 69% yield after separation by MPLC with hexane–AcOEt (10:1) as an eluent.

Colorless crystals. Mp 82–83 °C (hexane–AcOEt). IR ($CHCl_3$): 2320, 1646 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 0.08 (s, 9H), 4.19 (d, 1H, J=17.2 Hz), 5.20 (d, 1H, J=17.2 Hz),



Scheme 4.

7.04–7.25 (m, 6H), 7.34–7.40 (m, 2H), 7.52 (d, 1H, J=8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: −0.2, 38.5, 90.1, 100.2, 123.5, 127.7, 127.9, 128.2, 129.5, 130.1, 132.8, 133.5, 135.3, 140.7, 170.3. MS m/z: 385, 387 (M^+). Anal. Calcd for $C_{19}H_{20}BrNOSi$: C, 59.07; H, 5.22; N, 3.63. Found: C, 58.89; H, 5.28; N, 3.49.

3.1.5. *N*-But-2-yn-1-yl-2-iodo-*N*-methylbenzamide (6a). Treatment of 2-iodo-*N*-methyl-*N*-prop-2-yn-1-ylbenzamide (1.8 g, 6.3 mmol) with iodomethane (0.5 mL, 8 mmol) according to the literature[10] produced **6a** in 65% yield after separation by MPLC with hexane–AcOEt (3:1) as an eluent.

Viscous oil. IR ($CHCl_3$): 1632 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 1.79 and 1.83 (two s, 3H), 4.07 (dd, 1H, J=2.3, 16.7 Hz), 5.09 (d, 1H, J=16.7 Hz), 6.90–6.93 (m, 1H), 7.15–7.22 (m, 5H), 7.38 (d, 2H, J=7.5 Hz), 7.80 (d, 1H, J=7.5 Hz). ^{13}C NMR ($CDCl_3$) δ: 3.7, 32.1, 35.5, 35.9, 36.4, 41.1, 72.6, 73.1, 80.3, 81.3, 92.3, 92.6, 127.1, 128.5, 130.3, 139.3, 142.1, 142.3, 170.3. HRMS m/z Calcd for $C_{12}H_{12}INO$: 312.9964. Found: 312.9953.

3.1.6. 2-Iodo-*N*-methyl-*N*-[3-(trimethylsilyl)prop-2-yn-1-yl]benzamide (6b). Treatment of 2-iodo-*N*-methyl-*N*-prop-2-yn-1-ylbenzamide (1.8 g, 6.3 mmol) with chlorotrimethylsilane (1 mL, 8 mmol) according to the literature[10] produced **6b** in 60% yield after separation by MPLC with hexane–AcOEt (3:1) as an eluent.

Colorless crystals. Mp 53–54 °C (hexane–AcOEt). IR ($CHCl_3$): 1634 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 0.15 and 0.17 (two s, 9H), 2.88 and 3.18 (two s, 3H), 3.86 (d, 1H, J=7.5 Hz), 4.43 (s, 1H), 7.05–7.09 (m, 1H), 7.22 (dd, 1H, J=1.5, 8.0 Hz), 7.27 (dd, 1H, J=1.5, 8.0 Hz), 7.37–7.41 (m, 1H), 7.82 (dd, 1H, J=2.9, 8.1 Hz). ^{13}C NMR ($CDCl_3$) δ: −0.1, 32.2, 35.4, 36.9, 41.7, 89.6, 90.5, 92.3, 92.6, 99.2, 99.5, 127.1, 127.3, 128.4, 128.5, 130.3, 130.4, 139.3, 142.1, 170.3. MS m/z: 371 (M^+). MS m/z: 371 (M^+). Anal. Calcd for $C_{14}H_{18}INOSi$: C, 45.29; H, 4.89; N, 3.77. Found: C, 45.30; H, 4.74; N, 3.76.

3.1.7. (2*E*)-*N*-(2-Iodophenyl)-*N*-methylbut-2-enamide (11). Treatment of (2*E*)-*N*-(2-iodophenyl)but-2-enamide, readily available from 2-iodoaniline and *trans*-crotonyl chloride in 80% yield, with iodomethane according to a common procedure using sodium hydride gave **11** in 85% yield.

Colorless crystals. Mp 107–108 °C (hexane–AcOEt). IR ($CHCl_3$): 1664, 1620 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 1.73 (dd, 3H, J=1.8, 6.9 Hz), 3.21 (s, 3H), 5.48 (dd, 1H, J=1.8, 15.5 Hz), 6.94 (dq, 1H, J=6.9, 15.5 Hz), 7.08 (dt, 1H, J=1.8, 8.0 Hz), 7.24 (dd, 1H, J=1.8, 8.0 Hz), 7.41 (dt, 1H, J=1.8, 8.0 Hz), 7.93 (dd, 1H, J=1.8, 8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: 18.1, 36.1, 99.8, 122.2, 129.5, 129.7, 129.9, 140.2, 142.0, 145.9, 165.9. MS m/z: 301 (M^+). Anal. Calcd for $C_{11}H_{12}INO$: C, 43.87; H, 4.02; N, 4.65. Found: C, 43.83; H, 4.05; N, 4.54.

3.1.8. *N*,2-Dimethyl-*N*-(2-methylphenyl)acrylamide (14). Treatment of *N*-(2-iodophenyl)-2-methylacrylamide, readily available from 2-iodoaniline and methacryl chloride in 85% yield, with iodomethane according to a common procedure using sodium hydride gave **14** in 90% yield.

Colorless crystals. Mp 79–80 °C (hexane–AcOEt). IR ($CHCl_3$): 1648, 1622 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 1.81 (s, 3H), 3.23 (s, 3H), 4.97 (s, 1H), 5.04 (s, 1H), 7.00 (dt, 1H, J=1.2, 8.0 Hz), 7.16 (d, 1H, J=7.5 Hz), 7.34 (t, 1H, J=7.5 Hz), 7.86 (dd, 1H, J=1.2, 8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: 20.6, 36.9, 99.1, 119.1, 129.3, 129.4, 129.5, 140.3, 147.0, 171.8. MS m/z: 301 (M^+). Anal. Calcd for $C_{11}H_{12}INO$: C, 43.87; H, 4.02; N, 4.65. Found: C, 43.77; H, 4.02; N, 4.56.

3.1.9. *N*-(2-Iodophenyl)-*N*-(2-methylprop-2-en-1-yl)-acetamide (17). Treatment of *N*-(2-iodophenyl)acetamide, readily available from 2-iodoaniline and acetyl chloride, with methallyl chloride according to a common procedure using sodium hydride gave **17** in 80% yield.

Colorless crystals. Mp 68–69 °C (hexane–AcOEt). IR ($CHCl_3$): 1655 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 1.79 (s, 3H), 1.80 (s, 3H), 3.32 (d, 1H, J=14.9 Hz), 4.64 (s, 1H), 4.82 (s, 1H), 4.97 (d, 1H, J=14.9 Hz), 7.05 (t, 1H, J=7.5 Hz), 7.16 (dd, 1H, J=1.5, 7.5 Hz), 7.36 (t, 1H, J=7.5 Hz), 7.93 (d, 1H, J=8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: 20.7, 22.9, 54.0, 100.2, 114.2, 129.4, 129.8, 130.3, 140.4, 140.5, 144.8, 170.2. MS m/z: 315 (M^+). Anal. Calcd for $C_{12}H_{14}INO$: C, 45.73; H, 4.48; N, 4.44. Found: C, 45.88; H, 4.50; N, 4.31.

3.1.10. 2-Iodo-*N*-methyl-*N*-(2-methylprop-2-en-1-yl)benzamide (20). Treatment of 2-iodo-*N*-methylbenzamide, readily available from 2-iodobenzoyl chloride and methylamine, with methallyl chloride according to a common procedure using sodium hydride gave **20** in 78% yield.

Viscous oil. IR ($CHCl_3$): 1638 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 1.57 and 1.82 (two s, 3H), 2.73 and 3.04 (two s, 3H), 3.58 and 3.68 (two d, 1H, J=14.9 Hz), 4.12 (s, 1H), 4.85 and 4.90 (two s, 1H), 4.95 (s, 1H), 7.00–7.08 (m, 1H), 7.15–7.22 (m, 1H), 7.30–7.40 (m, 1H), 7.73–7.83 (m, 1H). ^{13}C NMR ($CDCl_3$) δ: 20.0, 20.5, 32.3, 35.6, 52.4, 56.8, 92.2, 92.9, 113.3, 113.4, 127.1, 127.3, 128.2, 128.4, 130.1, 130.2, 139.1, 139.3, 140.0, 140.2, 142.3, 143.0, 170.7, 171.2. HRMS m/z Calcd for $C_{12}H_{14}INO$: 315.0120. Found: 315.0133.

3.2. General procedure for the tandem cross-coupling reaction of indolylborate (2) with 3, 6, 9,[11] 11, 14, 17, and 20

To a THF solution of indolylborate (**2**) generated from indole (**1**) (2 mmol) in situ under an argon atmosphere, **3**, **6**, **9**, **11**, **14**, **17**, or **20** (1 mmol) and the palladium complex (0.05 mmol) were added at room temperature, and then, the whole was heated at 60 °C for the time indicated in Table 1. The mixture was ice-cooled, and 10% NaOH (10 mL) and 30% H_2O_2 (2 mL) were added. After stirring for 10 min, the mixture was diluted with AcOEt (100 mL), washed with brine, and dried over $MgSO_4$. The solvent was removed, and the residue was separated by MPLC with hexane–AcOEt.

3.2.1. 2-[(1*E*)-1-(1-Benzoyl-1,2-dihydro-3*H*-indol-3-ylidene)ethyl]-1-methyl-1*H*-indole (4a). Colorless crystals. Mp 180–181 °C (hexane–AcOEt). IR ($CHCl_3$): 1642 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 2.04 (br s, 3H), 3.53 (s, 3H), 4.82

(br s, 2H), 6.14 (d, 1H, J=7.8 Hz), 6.39 (s, 1H), 6.60–6.75 (m, 1H), 6.90–7.15 (m, 1H), 7.16 (t, 1H, J=7.8 Hz), 7.25 (t, 1H, J=7.8 Hz), 7.36 (d, 1H, J=7.8 Hz), 7.48–7.56 (m, 4H), 7.57–7.62 (m, 2H), 7.64 (d, 1H, J=7.8 Hz). ^{13}C NMR ($CDCl_3$) δ: 23.0, 29.6, 55.1, 99.1, 109.5, 118.4, 119.6, 120.5, 121.3, 122.8, 124.1, 126.7, 128.1, 128.5, 128.6, 129.0, 130.3, 133.4, 136.7, 136.8, 140.3, 168.4. MS m/z: 378 (M^+). Anal. Calcd for $C_{26}H_{22}N_2O$: C, 82.51; H, 5.86; N, 7.40. Found: C, 82.31; H, 5.99; N, 7.25.

3.2.2. 2-[(*Z*)-(1-Benzoyl-1,2-dihydro-3*H*-indol-3-ylidene)(trimethylsilyl)methyl]-1-methyl-1*H*-indole (4b). Colorless crystals. Mp 190–191 °C (hexane–AcOEt). IR ($CHCl_3$): 1642, 1600 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 0.06 (s, 9H), 3.49 (s, 3H), 4.90 (br s, 2H), 5.91 (d, 1H, J=8.3 Hz), 6.15 (s, 1H), 6.60–6.70 (m, 1H), 7.00–7.18 (m, 1H), 7.14 (t, 1H, J=7.8 Hz), 7.21 (t, 1H, J=7.8 Hz), 7.34 (d, 1H, J=8.3 Hz), 7.42–7.56 (m, 4H), 7.56–7.61 (m, 3H). ^{13}C NMR ($CDCl_3$) δ: −1.1, 29.6, 56.4, 97.8, 109.5, 119.4, 120.0, 120.6, 124.4, 126.8, 128.6, 128.7, 129.9, 130.0, 130.6, 136.7, 136.9, 140.0, 147.0, 168.3. MS m/z: 436 (M^+). Anal. Calcd for $C_{28}H_{28}N_2OSi$: C, 74.02; H, 6.46; N, 6.42. Found: C, 76.87; H, 6.46; N, 6.49.

3.2.3. 2-[(*E*)-(1-Benzoyl-1,2-dihydro-3*H*-indol-3-ylidene)methyl]-1-methyl-1*H*-indole (4c). Colorless crystals. Mp 171–172 °C (hexane–AcOEt). IR ($CHCl_3$): 1642, 1590 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 3.65 (s, 3H), 4.86 (br s, 2H), 6.40 (br s, 1H), 6.65 (s, 1H), 6.80–6.90 (m, 1H), 7.14 (dt, 1H, J=1.2, 7.8 Hz), 7.20–7.25 (m, 1H), 7.23 (dt, 1H, J=1.0, 7.8 Hz), 7.33 (d, 1H, J=7.8 Hz), 7.46–7.56 (m, 5H), 7.57–7.62 (m, 2H), 7.62 (d, 1H, J=7.8 Hz). ^{13}C NMR ($CDCl_3$) δ: 30.3, 57.2, 101.7, 109.5, 109.7, 119.9, 120.6, 121.8, 123.9, 124.1, 127.1, 128.0, 128.6, 128.9, 130.5, 130.6, 135.4, 136.9, 137.4, 137.7, 137.8, 168.6. MS m/z: 364 (M^+). Anal. Calcd for $C_{25}H_{20}N_2O$: C, 82.39; H, 5.53; N, 7.69. Found: C, 82.45; H, 5.72; N, 7.69.

3.2.4. 2-[(1*E*)-1-(1-Benzoyl-1,2-dihydro-3*H*-indol-3-ylidene)ethyl]-1-methoxy-1*H*-indole (4d). Colorless crystals. Mp 124–125 °C (hexane–AcOEt). IR ($CHCl_3$): 1640 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 2.16 (br s, 3H), 3.89 (s, 3H), 4.81 (br s, 2H), 6.30 (s, 1H), 6.73 (br s, 1H), 6.83 (d, 1H, J=8.0 Hz), 7.05–7.15 (m, 1H), 7.15 (t, 1H, J=7.5 Hz), 7.27 (t, 1H, J=7.5 Hz), 7.46 (d, 1H, J=8.0 Hz), 7.49–7.55 (m, 4H), 7.57–7.69 (m, 3H). ^{13}C NMR ($CDCl_3$) δ: 22.4, 55.4, 65.8, 97.3, 108.6, 117.2, 120.4, 121.1, 122.4, 123.5, 124.0, 127.0, 128.8, 129.2, 129.3, 129.5, 130.6, 132.4, 133.5, 136.4, 136.9, 168.7. MS m/z: 394 (M^+). Anal. Calcd for $C_{26}H_{22}N_2O_2$: C, 79.16; H, 5.62; N, 7.10. Found: C, 79.10; H, 5.78; N, 6.97.

3.2.5. 2-[(*Z*)-(1-Benzoyl-1,2-dihydro-3*H*-indol-3-ylidene)(trimethylsilyl)methyl]-1-methoxy-1*H*-indole (4e). Viscous oil. IR (neat): 1646, 1600 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 0.06 (s, 9H), 3.90 (s, 3H), 4.84 (br s, 2H), 6.02 (s, 1H), 6.60 (d, 1H, J=7.5 Hz), 6.67–6.74 (m, 1H), 7.08–7.18 (m, 1H), 7.13 (t, 1H, J=7.5 Hz), 7.22 (t, 1H, J=7.5 Hz), 7.45 (d, 1H, J=8.0 Hz), 7.35–7.65 (m, 7H). ^{13}C NMR ($CDCl_3$) δ: −0.12, 56.8, 65.8, 94.7, 108.3, 120.0, 120.7, 121.4, 124.1, 124.3, 124.9, 127.0, 128.8, 130.7, 132.2, 136.8, 137.0, 146.6, 168.4. HRMS m/z Calcd for $C_{28}H_{28}N_2O_2$: 452.1920. Found: 452.1916.

3.2.6. *tert*-Butyl 2-[(1*E*)-1-(1-Benzoyl-1,2-dihydro-3*H*-indol-3-ylidene)ethyl]-1*H*-indole-1-carboxylate (4f). Colorless crystals. Mp 177–178 °C (AcOEt–hexane). IR ($CHCl_3$): 1724, 1640 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 1.49 (s, 9H), 1.98 (br s, 3H), 4.73 (br s, 2H), 6.45 (s, 1H), 6.57 (d, 1H, J=8.0 Hz), 6.69 (br s, 1H), 7.26 (t, 1H, J=7.5 Hz), 7.34 (t, 1H, J=7.5 Hz), 7.48–7.60 (m, 7H), 8.24 (d, 1H, J=8.5 Hz). ^{13}C NMR ($CDCl_3$) δ: 22.9, 28.1, 50.5, 83.6, 107.9, 115.9, 120.7, 123.0, 123.1, 124.2, 124.3, 127.0, 128.7, 128.9, 129.6, 130.5, 136.4, 137.1, 139.5, 149.8, 168.8. MS m/z: 464 (M^+). Anal. Calcd for $C_{30}H_{28}N_2O_3$: C, 77.56; H, 6.08; N, 6.03. Found: C, 77.48; H, 6.20; N, 5.87.

3.2.7. (3*E*)-1-Benzoyl-3-(1-methylpropylidene)indoline (5a). Viscous oil. IR (neat): 1666, 1580 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 1.13 (t, 3H, J=7.4 Hz), 1.71 (br s, 3H), 2.46 (q, 2H, J=7.4 Hz), 4.56 (br s, 2H), 7.04 (br s, 1H), 7.43–7.58 (m, 8H). ^{13}C NMR ($CDCl_3$) δ: 11.7, 21.3, 27.5, 55.7, 117.3, 123.5, 123.9, 124.1, 125.1, 126.9, 127.4, 128.7, 137.1, 145.5, 168.5. HRMS m/z Calcd for $C_{19}H_{19}NO$: 277.1467. Found: 277.1470.

3.2.8. (3*Z*)-1-Benzoyl-3-[1-(trimethylsilyl)propylidene]-indoline (5b). Viscous oil. IR ($CHCl_3$): 1636, 1598 cm^{-1}. ^{1}H NMR (acetone-d_6) δ: 0.05 (s, 9H), 1.09 (t, 3H, J=7.5 Hz), 2.55 (q, 2H, J=7.5 Hz), 4.67 (s, 2H), 7.08 (t, 1H, J=8.0 Hz), 7.38 (br s, 1H), 7.45–7.54 (m, 4H), 7.58–7.64 (m, 2H), 7.68 (d, 1H, J=7.5 Hz). ^{13}C NMR (acetone-d_6) δ: −1.1, 13.1, 24.2, 57.1, 117.3, 123.9, 125.4, 126.8, 128.5, 128.8, 130.1, 130.6, 135.4, 137.6, 140.2, 146.1, 167.8. HRMS m/z Calcd for $C_{21}H_{25}NOSi$: 335.1705. Found: 335.1701.

3.2.9. (4*E*)-2-Methyl-4-[1-(1-methyl-1*H*-indol-2-yl)ethylidene]-3,4-dihydroisoquinolin-1(2*H*)-one (7a). Colorless crystals. Mp 181–182 °C (hexane–AcOEt). IR ($CHCl_3$): 1638 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 2.31 (s, 3H), 3.05 (s, 3H), 3.27 (s, 3H), 4.36 (d, 2H, J=5.2 Hz), 6.38 (d, 1H, J=7.5 Hz), 6.51 (s, 1H), 6.95 (dt, 1H, J=1.2, 7.5 Hz), 7.11–7.14 (m, 2H), 7.17–7.22 (m, 2H), 7.60 (d, 1H, J=8.0 Hz), 8.07 (dd, 1H, J=1.2, 8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: 22.6, 30.0, 35.0, 51.4, 101.6, 109.7, 119.9, 120.4, 121.8, 125.8, 126.3, 127.6, 127.7, 127.8, 128.8, 131.1, 136.4, 137.2, 140.7, 164.1. MS m/z: 316 (M^+). Anal. Calcd for $C_{21}H_{20}N_2O$: C, 79.71; H, 6.37; N, 8.85. Found: C, 79.51; H, 6.61; N, 8.82.

3.2.10. (4*Z*)-2-Methyl-4-[(1-methyl-1*H*-indol-2-yl)(trimethylsilyl)methylene]-3,4-dihydroisoquinolin-1(2*H*)-one (7b). Viscous oil. IR (neat): 1646 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 0.01 (s, 9H), 3.00 (s, 3H), 3.59 (s, 3H), 3.65 (d, 1H, J=13.5 Hz), 3.98 (d, 1H, J=13.5 Hz), 6.18 (s, 1H), 7.14 (t, 1H, J=7.5 Hz), 7.22 (t, 1H, J=7.5 Hz), 7.33 (d, 1H, J=8.0 Hz), 7.51–7.53 (m, 2H), 7.59–7.63 (m, 2H), 8.10–8.12 (m, 1H). ^{13}C NMR ($CDCl_3$) δ: 0.44, 30.1, 34.9, 54.0, 99.8, 109.4, 119.8, 120.2, 121.0, 126.9, 128.1, 128.5, 129.7, 129.9, 130.7, 136.0, 137.1, 137.2, 140.6, 146.6, 164.5. HRMS m/z Calcd for $C_{23}H_{26}N_2OSi$: 374.1814. Found: 374.1805.

3.2.11. (4*E*)-4-[1-(1-Methoxy-1*H*-indol-2-yl)ethylidene]-2-methyl-3,4-dihydroisoquinolin-1(2*H*)-one (7c). Colorless crystals. Mp 170–171 °C (hexane–AcOEt). IR ($CHCl_3$): 1640 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 2.32 (s, 3H),

3.26 (s, 3H), 3.78 (s, 3H), 4.33 (s, 2H), 6.23 (s, 1H), 6.72 (d, 1H, *J*=8.0 Hz), 7.01 (t, 1H, *J*=7.5 Hz), 7.10 (t, 1H, *J*=7.5 Hz), 7.19–7.24 (m, 2H), 7.31 (d, 1H, *J*=8.0 Hz), 7.51 (d, 1H, *J*=8.0 Hz), 8.07 (d, 1H, *J*=8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: 21.4, 35.2, 51.5, 65.2, 99.0, 108.6, 120.4, 121.0, 122.6, 123.4, 123.8, 126.4, 127.7, 127.9, 128.8, 128.9, 130.8, 132.7, 136.8, 136.9, 164.5. MS *m/z*: 332 (M^+). Anal. Calcd for $C_{21}H_{20}N_2O_2\cdot 1/10H_2O$: C, 75.47; H, 6.09; N, 8.38. Found: C, 75.51; H, 6.19; N, 8.28.

3.2.12. (4*Z*)-4-[(1-Methoxy-1*H*-indol-2-yl)(trimethylsilyl)methylene]-2-methyl-3,4-dihydro-isoquinolin-1(2*H*)-one (7d). Viscous oil. IR ($CHCl_3$): 1640 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 0.00 (s, 9H), 3.04 (s, 3H), 3.98 (s, 3H), 3.95–4.01 (m, 1H), 4.09–4.15 (m, 1H), 6.05 (s, 1H), 7.13 (t, 1H, *J*=7.5 Hz), 7.23 (t, 1H, *J*=7.5 Hz), 7.42 (d, 1H, *J*=8.0 Hz), 7.45–7.55 (m, 2H), 7.56 (d, 1H, *J*=8.0 Hz), 7.65–7.69 (m, 1H), 8.08–8.14 (m, 1H). ^{13}C NMR ($CDCl_3$) δ: 0.98, 34.6, 54.0, 65.3, 96.9, 108.2, 120.4, 120.5, 121.8, 124.1, 126.7, 128.1, 129.6, 129.9, 130.6, 132.4, 133.5, 137.3, 137.5, 146.5, 164.4. HRMS *m/z* Calcd for $C_{23}H_{26}N_2O_2Si$: 390.1764. Found: 390.1752.

3.2.13. *tert*-Butyl 2-[(1*E*)-1-(2-methyl-1-oxo-2,3-dihydroisoquinolin-4(1*H*)-ylidene)ethyl]-1*H*-indole-1-carboxylate (7e). Colorless crystals. Mp 166–167 °C (hexane–AcOEt). IR ($CHCl_3$): 1722, 1636 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 1.59 (s, 9H), 2.16 (s, 3H), 3.24 (s, 3H), 4.27 (d, 2H, *J*=4.0 Hz), 6.13 (s, 1H), 6.79 (d, 1H, *J*=8.0 Hz), 7.03 (t, 1H, *J*=7.5 Hz), 7.18 (t, 1H, *J*=7.5 Hz), 7.20 (t, 1H, *J*=7.5 Hz), 7.29 (t, 1H, *J*=7.5 Hz), 7.37 (d, 1H, *J*=7.5 Hz), 8.05 (d, 1H, *J*=7.5 Hz), 8.18 (d, 1H, *J*=8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: 21.6, 28.1, 35.1, 50.9, 84.1, 108.8, 115.5, 120.9, 123.0, 124.3, 125.8, 126.7, 127.5, 127.8, 128.6, 128.9, 129.4, 130.8, 136.5, 136.7, 140.5, 149.8, 164.4. MS *m/z*: 402 (M^+). Anal. Calcd for $C_{25}H_{26}N_2O_3\cdot 2/3H_2O$: C, 72.44; H, 6.65; N, 6.76. Found: C, 72.65; H, 6.43; N, 6.72.

3.2.14. (4*E*)-2-Methyl-4-(1-methylpropylidene)-3,4-dihydroisoquinolin-1(2*H*)-one (8a). Colorless crystals. Mp 100–101 °C (hexane–AcOEt). IR ($CHCl_3$): 1632, 1600 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 1.17 (t, 3H, *J*=7.5 Hz), 1.92 (s, 3H), 2.35 (q, 2H, *J*=7.5 Hz), 3.17 (s, 3H), 4.09 (s, 2H), 7.26–7.38 (m, 2H), 7.43 (dt, 1H, *J*=1.1, 7.5 Hz), 8.07 (dd, 1H, *J*=1.5, 7.8 Hz). ^{13}C NMR ($CDCl_3$) δ: 13.0, 18.5, 27.7, 34.9, 51.1, 122.7, 126.7, 127.0, 127.9, 129.5, 130.5, 137.3, 137.7, 164.6. MS *m/z*: 215 (M^+). Anal. Calcd for $C_{14}H_{17}NO$: C, 78.10; H, 7.96; N, 6.51. Found: C, 78.21; H, 8.08; N, 6.43.

3.2.15. (4*Z*)-2-Methyl-4-[1-(trimethylsilyl)propylidene]-3,4-dihydroisoquinolin-1(2*H*)-one (8b). Viscous oil. IR (neat): 1642, 1598 cm^{-1}. ^{1}H NMR (acetone-d_6) δ: 0.06 (s, 9H), 0.84 (t, 3H, *J*=7.5 Hz), 2.17 (q, 2H, *J*=7.5 Hz), 2.86 (s, 3H), 3.90 (s, 2H), 7.11–7.30 (m, 3H), 7.73 (dd, 1H, *J*=1.5, 8.3 Hz). ^{13}C NMR ($CDCl_3$) δ: 1.2, 15.9, 25.8, 34.3, 55.6, 127.5, 128.5, 128.6, 131.0, 131.3, 138.3, 138.5, 145.3, 164.5. HRMS *m/z* Calcd for $C_{16}H_{23}NOSi$: 273.1549. Found: 273.1547.

3.2.16. Diethyl (4*Z*)-4-[1-(1-methyl-1*H*-indol-2-yl)ethylidene]-3,4-dihydronaphthalene-2,2(1*H*)-dicarboxylate (10a). Viscous oil. IR (neat): 1732 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 1.10–1.35 (m, 6H), 2.26 (s, 3H), 3.00 (s, 3H), 3.15–3.45 (m, 2H), 4.10–4.30 (m, 4H), 6.39 (s, 1H), 6.42 (d, 1H, *J*=8.0 Hz), 6.64 (t, 1H, *J*=7.5 Hz), 6.97 (dt, 1H, *J*=1.0, 7.3 Hz), 7.05–7.16 (m, 4H), 7.57 (d, 1H, *J*=7.5 Hz). ^{13}C NMR ($CDCl_3$) δ: 14.0, 22.8, 29.8, 34.7, 35.6, 54.8, 61.5, 100.4, 109.4, 119.4, 120.1, 121.0, 124.5, 125.9, 126.8, 127.7, 128.0, 128.1, 131.7, 134.3, 135.7, 136.9, 142.8, 170.9. HRMS *m/z* Calcd for $C_{27}H_{29}NO_4$: 431.2097. Found: 431.2112.

3.2.17. Diethyl (4*E*)-4-[(1-methyl-1*H*-indol-2-yl)(trimethylsilyl)methylene]-3,4-dihydronaphthalene-2,2(1*H*)-dicarboxylate (10b). Viscous oil. IR (neat): 1732 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 0.18 (s, 9H), 1.18 (t, 3H, *J*=7.3 Hz), 1.24 (t, 3H, *J*=7.3 Hz), 3.22 (s, 3H), 3.26 (s, 2H), 3.34 (d, 1H, *J*=15.0 Hz), 3.49 (d, 1H, *J*=15.0 Hz), 3.91–4.09 (m, 4H), 6.10 (s, 1H), 6.60–6.75 (m, 2H), 6.97 (dt, 1H, *J*=2.0, 7.5 Hz), 7.04–7.10 (m, 1H), 7.10 (dt, 1H, *J*=1.0, 7.5 Hz), 7.14 (d, 1H, *J*=7.5 Hz), 7.51 (d, 1H, *J*=7.5 Hz). ^{13}C NMR ($CDCl_3$) δ: 0.49, 14.0, 29.5, 34.0, 37.7, 54.6, 61.6, 99.5, 108.9, 119.1, 119.8, 120.0, 126.4, 127.6, 128.1, 128.4, 131.8, 134.9, 136.0, 136.7, 141.7, 150.0, 170.0, 171.0. HRMS *m/z* Calcd for $C_{27}H_{29}NO_4$: 489.2336. Found: 489.2342.

3.2.18. 3-Ethyl-1-methyl-1,3-dihydro-2*H*-indol-2-one (12). Viscous oil. IR ($CHCl_3$): 1696 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 0.88 (t, 3H, *J*=7.5 Hz), 1.95–2.08 (m, 2H), 3.19 (s, 3H), 3.40 (t, 1H, *J*=5.7 Hz), 6.82 (d, 1H, *J*=7.5 Hz), 7.05 (t, 1H, *J*=7.5 Hz), 7.24–7.30 (m, 2H). ^{13}C NMR ($CDCl_3$) δ: 10.2, 23.8, 26.2, 46.7, 107.9, 122.3, 123.9, 127.9, 129.1, 140.2, 178.1. HRMS *m/z* Calcd for $C_{11}H_{13}NO$: 175.0997. Found: 175.0981.

3.2.19. 3-[1-(2-Ethyl-1-methyl-1*H*-indol-3-yl)ethyl]-1-methyl-1,3-dihydro-2*H*-indol-2-one (13). Colorless crystals. Mp 198–199 °C (hexane–AcOEt). IR ($CHCl_3$): 1692 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 0.82 (t, 3H, *J*=7.5 Hz), 1.86 (d, 3H, *J*=6.9 Hz), 2.49 (q, 2H, *J*=7.5 Hz), 3.16 (s, 3H), 3.17–3.22 (m, 1H), 3.66 (s, 3H), 3.88 (d, 1H, *J*=10.4 Hz), 6.03 (d, 1H, *J*=6.9 Hz), 6.65 (t, 1H, *J*=7.5 Hz), 6.69 (d, 1H, *J*=7.5 Hz), 7.02 (t, 1H, *J*=7.5 Hz), 7.12 (t, 1H, *J*=7.5 Hz), 7.16 (t, 1H, *J*=7.5 Hz), 7.30 (d, 1H, *J*=8.0 Hz), 7.61 (d, 1H, *J*=8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: 14.1, 17.6, 19.2, 26.1, 29.6, 34.9, 50.0, 107.4, 109.0, 112.9, 118.9, 119.9, 120.6, 121.6, 125.6, 126.2, 127.6, 128.8, 137.1, 139.2, 144.2, 177.6. MS *m/z*: 332 (M^+). Anal. Calcd for $C_{22}H_{24}N_2O\cdot 1/5H_2O$: C, 78.63; H, 7.32; N, 8.34. Found: C, 78.64; H, 7.38; N, 8.33.

3.2.20. 1,3-Dimethyl-3-[(1-methyl-1*H*-indol-2-yl)-methyl]-1,3-dihydro-2*H*-indol-2-one (15a). Colorless crystals. Mp 106–107 °C (hexane–AcOEt). IR ($CHCl_3$): 1708 cm^{-1}. ^{1}H NMR ($CDCl_3$) δ: 1.50 (s, 3H), 3.09 (s, 3H), 3.14 (d, 1H, *J*=14.6 Hz), 3.22 (d, 1H, *J*=14.6 Hz), 3.36 (s, 3H), 6.02 (s, 1H), 6.72 (d, 1H, *J*=7.5 Hz), 6.90 (d, 1H, *J*=7.3 Hz), 6.95 (t, 1H, *J*=7.3 Hz), 7.02 (t, 1H, *J*=7.3 Hz), 7.11 (t, 1H, *J*=7.8 Hz), 7.16 (d, 1H, *J*=8.0 Hz), 7.21 (t, 1H, *J*=7.8 Hz), 7.44 (d, 1H, *J*=7.5 Hz). ^{13}C NMR ($CDCl_3$) δ: 22.9, 26.0, 29.6, 33.9, 48.6, 101.7, 108.0, 109.1, 119.1, 119.9, 120.7, 122.2, 123.1, 127.5, 128.0, 132.8, 135.2, 136.9, 143.1, 179.9. MS *m/z*: 304 (M^+). Anal. Calcd for $C_{20}H_{20}N_2O$: C, 78.92; H, 6.62; N, 9.20. Found: C, 78.89; H, 6.73; N, 9.08.

3.2.21. 3-[(1-Methoxy-1*H*-indol-2-yl)methyl]-1,3-dimethyl-1,3-dihydro-2*H*-indol-2-one (15b). Colorless crystals. Mp 121–122 °C (hexane–AcOEt). IR ($CHCl_3$): 1702 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.55 (s, 3H), 3.17 (s, 3H), 3.32 (s, 2H), 3.92 (s, 3H), 5.73 (s, 1H), 6.78 (d, 1H, J=7.5 Hz), 6.99–7.06 (m, 2H), 7.11 (d, 1H, J=7.5 Hz), 7.16 (t, 1H, J=7.5 Hz), 7.25 (t, 1H, J=8.0 Hz), 7.33 (d, 1H, J=8.0 Hz), 7.41 (d, 1H, J=8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: 23.9, 26.4, 32.5, 48.5, 65.0, 97.4, 108.2, 108.3, 120.0, 120.5, 121.6, 122.5, 123.4, 123.9, 128.2, 131.6, 132.4, 133.2, 143.3, 180.1. MS *m/z*: 320 (M^+). Anal. Calcd for $C_{20}H_{20}N_2O_2$: C, 74.98; H, 6.29; N, 8.74. Found: C, 74.89; H, 6.37; N, 8.65.

3.2.22. *tert*-Butyl 2-[(1,3-dimethyl-2-oxo-2,3-dihydro-1*H*-indol-3-yl)methyl]-1*H*-indole-1-carboxylate (15c). Viscous oil. IR (neat): 1708 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.44 (s, 3H), 1.55 (s, 9H), 3.16 (s, 3H), 3.62 (d, 1H, J=14.9 Hz), 3.82 (d, 1H, J=14.9 Hz), 6.22 (s, 1H), 6.74 (d, 1H, J=8.0 Hz), 6.92–6.96 (m, 2H), 7.11–7.21 (m, 3H), 7.38 (d, 1H, J=7.5 Hz), 7.93 (d, 1H, J=8.5 Hz). ^{13}C NMR ($CDCl_3$) δ: 23.6, 26.3, 28.2, 35.8, 48.8, 83.9, 108.0, 109.9, 115.8, 120.0, 122.4, 122.6, 123.4, 123.6, 127.9, 128.9, 133.4, 136.5, 136.9, 143.1, 150.6, 180.4. HRMS *m/z* Calcd for $C_{24}H_{26}N_2O_3$: 390.1943. Found: 390.1951.

3.2.23. 2-[(1-Acetyl-3-methyl-2,3-dihydro-1*H*-indol-3-yl)methyl]-1-methyl-1*H*-indole (18a). Colorless crystals. Mp 151–152 °C (hexane–AcOEt). IR ($CHCl_3$): 1652 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.51 (s, 3H), 2.23 (s, 3H), 3.01 (d, 1H, J=18.0 Hz), 3.06 (d, 1H, J=18.0 Hz), 3.15 (s, 3H), 3.76 (d, 1H, J=10.3 Hz), 4.07 (d, 1H, J=10.3 Hz), 6.31 (s, 1H), 6.73 (d, 1H, J=7.5 Hz), 6.94 (t, 1H, J=7.5 Hz), 7.10 (t, 1H, J=7.5 Hz), 7.16–7.24 (m, 3H), 7.56 (d, 1H, J=7.5 Hz), 8.21 (d, 1H, J=8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: 24.3, 25.1, 29.3, 37.8, 44.4, 62.0, 101.9, 109.4, 117.1, 119.7, 120.0, 121.1, 122.8, 123.9, 127.6, 128.5, 136.2, 137.3, 138.0, 142.1, 168.9. MS *m/z*: 318 (M^+). Anal. Calcd for $C_{21}H_{22}N_2O$: C, 79.21; H, 6.96; N, 8.80. Found: C, 79.48; H, 7.07; N, 8.73.

3.2.24. *tert*-Butyl 2-[(1-acetyl-3-methyl-2,3-dihydro-1*H*-indol-3-yl)methyl]-1*H*-indole-1-carboxylate (18b). Colorless crystals. Mp 167–168 °C (hexane–AcOEt). IR ($CHCl_3$): 1724, 1648 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.44 (s, 3H), 1.65 (s, 9H), 2.17 (s, 3H), 3.35 (d, 1H, J=14.9 Hz), 3.67 (d, 1H, J=10.3 Hz), 3.75 (d, 1H, J=14.9 Hz), 4.09 (d, 1H, J= 10.3 Hz), 6.14 (s, 1H), 7.00–7.08 (m, 2H), 7.16–7.28 (m, 3H), 7.42 (d, 1H, J=8.0 Hz), 7.99 (d, 1H, J=8.0 Hz), 8.18 (d, 1H, J=8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: 24.3, 26.8, 28.3, 38.7, 44.7, 61.2, 84.3, 110.4, 115.8, 117.1, 120.1, 122.6, 122.9, 123.8, 128.1, 128.9, 136.4, 137.6, 138.8, 142.1, 150.9, 168.7. MS *m/z*: 404 (M^+). Anal. Calcd for $C_{25}H_{28}N_2O_3$: C, 74.23; H, 6.98; N, 6.93. Found: C, 74.23; H, 6.98; N, 6.93.

3.2.25. *N*-[2-(1-Methyl-1*H*-indol-2-yl)phenyl]-*N*-(2-methylprop-2-en-1-yl)acetamide (19a). Colorless crystals. Mp 120–121 °C (hexane–AcOEt). IR ($CHCl_3$): 1648 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.61 (s, 3H), 2.00 (s, 3H), 3.07 (d, 1H, J=15.0 Hz), 3.61 (s, 3H), 4.54 (s, 1H), 4.64 (d, 1H, J=15.0 Hz), 4.71 (s, 1H), 6.44 (s, 1H), 7.15 (t, 1H, J= 7.5 Hz), 7.24–7.30 (m, 2H), 7.35–7.45 (m, 4H), 7.62 (d, 1H, J=8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: 20.5, 23.0, 31.1, 54.0, 102.7, 109.6, 113.4, 120.2, 121.0, 122.2, 127.9, 128.0, 129.3, 130.5, 132.8, 136.2, 137.9, 140.9, 141.9, 170.5. MS *m/z*: 318 (M^+). Anal. Calcd for $C_{21}H_{22}N_2O$: C, 79.21; H, 6.96; N, 8.80. Found: C, 79.48; H, 7.07; N, 8.73.

3.2.26. *N*-[2-(1-Methoxy-1*H*-indol-2-yl)phenyl]-*N*-(2-methylprop-2-en-1-yl)acetamide (19b). Colorless crystals. Mp 168–169 °C (hexane–AcOEt). IR (neat): 1644 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.67 (s, 3H), 2.01 (s, 3H), 3.05 (d, 1H, J=14.9 Hz), 3.70 (s, 3H), 4.56 (s, 1H), 4.72 (s, 1H), 4.81 (d, 1H, J=14.9 Hz), 6.41 (s, 1H), 7.15 (t, 1H, J=7.5 Hz), 7.24–7.30 (m, 2H), 7.40–7.49 (m, 3H), 7.60 (d, 1H, J=8.0 Hz), 7.80 (dd, 1H, J=1.7, 7.5 Hz). ^{13}C NMR ($CDCl_3$) δ: 20.7, 22.9, 53.2, 64.5, 100.4, 109.1, 113.3, 120.9, 121.3, 123.2, 124.3, 128.1, 128.2, 129.1, 130.7, 131.9, 132.7, 133.3, 140.8, 141.0, 170.9. MS *m/z*: 334 (M^+). Anal. Calcd for $C_{21}H_{22}N_2O_2 \cdot 1/10H_2O$: C, 75.02; H, 6.66; N, 8.33. Found: C, 74.98; H, 6.61; N, 8.36.

3.2.27. 2,4-Dimethyl-4-[(1-methyl-1*H*-indol-2-yl)-methyl]-3,4-dihydroisoquinolin-1(2*H*)-one (21a). Colorless crystals. Mp 118–119 °C (hexane–AcOEt). IR ($CHCl_3$): 1638 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.43 (s, 3H), 2.95 (d, 1H, J=14.5 Hz), 3.01 (s, 3H), 3.23 (s, 3H), 3.24 (d, 1H, J=14.5 Hz), 3.27 (d, 1H, J=12.6 Hz), 3.62 (d, 1H, J=12.6 Hz), 6.29 (s, 1H), 6.86 (d, 1H, J=8.0 Hz), 7.07–7.12 (m, 1H), 7.13–7.17 (m, 2H), 7.29 (dt, 1H, J=1.8, 8.0 Hz), 7.36 (dt, 1H, J=1.2, 7.5 Hz), 7.56 (d, 1H, J=8.0 Hz), 8.18 (dd, 1H, J=1.2, 8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: 22.7, 29.1, 35.6, 36.0, 38.3, 59.0, 102.9, 109.4, 119.6, 119.9, 121.1, 124.7, 127.4, 127.6, 128.4, 128.7, 132.0, 135.8, 137.3, 144.4, 164.7. MS *m/z*: 318 (M^+). Anal. Calcd for $C_{21}H_{22}N_2O \cdot 3/10H_2O$: C, 77.89; H, 7.03; N, 8.65. Found: C, 77.99; H, 6.92; N, 8.54.

3.2.28. 4-[(1-Methoxy-1*H*-indol-2-yl)methyl]-2,4-dimethyl-3,4-dihydroisoquinolin-1(2*H*)-one (21b). Viscous oil. IR (neat): 1648, 1602 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.38 (s, 1H), 2.99 (d, 1H, J=14.5 Hz), 3.15 (d, 1H, J=14.5 Hz), 3.21 (s, 3H), 3.31 (d, 1H, J=12.6 Hz), 3.40 (d, 1H, J=12.6 Hz), 3.85 (s, 3H), 6.02 (s, 1H), 7.11 (t, 1H, J=7.5 Hz), 7.22 (t, 1H, J=7.5 Hz), 7.28 (d, 1H, J=7.5 Hz), 7.38 (t, 2H, J=7.5 Hz), 7.47 (dt, 1H, J=1.7, 7.5 Hz), 7.54 (d, 1H, J=8.0 Hz), 8.19 (dd, 1H, J=1.7, 7.5 Hz). ^{13}C NMR ($CDCl_3$) δ: 22.7, 34.9, 35.4, 38.3, 57.3, 64.6, 99.1, 108.4, 120.4, 120.5, 121.9, 123.9, 124.2, 127.3, 128.3, 128.7, 131.8, 132.0, 132.5, 145.5, 164.7. HRMS *m/z* Calcd for $C_{21}H_{22}N_2O_2$: 334.1681. Found: 334.1678.

3.2.29. *tert*-Butyl 2-[(2,4-dimethyl-1-oxo-1,2,3,4-tetrahydroisoquinolin-4-yl)methyl]-1*H*-indole-1-carboxylate (21c). Colorless crystals. Mp 141–142 °C (hexane–AcOEt). IR ($CHCl_3$): 1728, 1646 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.32 (s, 3H), 1.69 (s, 9H), 3.18 (s, 3H), 3.37 (d, 1H, J=12.6 Hz), 3.38 (d, 1H, J=14.8 Hz), 3.42 (d, 1H, J=12.6 Hz), 3.80 (d, 1H, J=14.8 Hz), 6.01 (s, 1H), 7.10 (d, 1H, J=7.4 Hz), 7.18 (t, 1H, J=7.4 Hz), 7.23 (d, 1H, J=7.4 Hz), 7.34 (t, 1H, J=7.4 Hz), 7.38 (dt, 1H, J=1.1, 7.4 Hz), 7.42 (d, 1H, J=7.4 Hz), 7.97 (d, 1H, J=8.5 Hz), 8.14 (dd, 1H, J=1.1, 8.5 Hz). ^{13}C NMR ($CDCl_3$) δ: 22.5, 28.4, 35.5, 36.8, 38.7, 58.2, 84.3, 111.3, 115.7, 120.1, 122.8, 123.7, 124.6, 127.0, 128.3, 128.6, 128.8, 131.7, 136.6, 137.5, 145.2, 150.9, 164.8. MS *m/z*: 404 (M^+). Anal. Calcd for $C_{25}H_{28}N_2O_3$: C, 74.23; H, 6.98; N, 6.93. Found: C, 74.16; H, 7.07; N, 6.81.

3.2.30. *N*-Methyl-2-(1-methyl-1*H*-indol-2-yl)-*N*-(2-methylprop-2-en-1-yl)benzamide (22a). Viscous oil. IR (neat): 1638 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.28 and 1.47 (two s, 3H), 2.55 and 2.75 (two s, 3H), 2.88–3.04 (two br s, 1H), 3.63 (s, 3H), 4.44 and 4.56 (two s, 1H), 4.60 and 4.74 (two s, 1H), 4.85–4.98 (m, 1H), 6.51 and 6.55 (two s, 1H), 7.07–7.15 (m, 1H), 7.20–7.27 (m, 1H), 7.30–7.50 (m, 4H), 7.55–7.64 (m, 1H). ^{13}C NMR ($CDCl_3$) δ: 19.4, 19.7, 28.1, 28.2, 31.2, 32.1, 35.6, 52.3, 56.6, 102.2, 103.0, 109.7, 112.5, 113.0, 119.8, 120.6, 120.8, 121.8, 126.8, 127.3, 127.9, 128.4, 128.5, 128.6, 128.7, 128.9, 129.6, 130.9, 131.3, 137.6, 138.0, 138.3, 138.5, 139.9, 140.0, 170.1, 171.2. HRMS *m/z* Calcd for $C_{21}H_{22}N_2O$: 318.1732. Found: 318.1728.

3.2.31. 2-(1-Methoxy-1*H*-indol-2-yl)-*N*-methyl-*N*-(2-methylprop-2-en-1-yl)benzamide (22b). Viscous oil. IR (neat): 1630 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.51 and 1.60 (two s, 3H), 2.66 and 2.93 (two s, 3H), 3.18–3.25 (m, 1H), 3.78 (s, 3H), 3.95–4.15 (m, 1H), 4.70 and 4.74 (two s, 1H), 4.82 (s, 1H), 6.51 and 6.52 (two s, 1H), 7.09–7.15 (m, 1H), 7.22–7.29 (m, 1H), 7.38–7.51 (m, 4H), 7.56 and 7.57 (two d, 1H, J=8.0 Hz), 7.75 (d, 1H, J=8.3 Hz). ^{13}C NMR ($CDCl_3$) δ: 19.8, 20.0, 32.3, 35.8, 52.5, 56.7, 64.7, 100.3, 100.6, 108.8, 113.1, 120.6, 120.7, 121.2, 121.3, 122.8, 122.9, 124.1, 127.2, 127.3, 127.4, 127.5, 128.3, 128.5, 128.9, 129.0, 130.2, 130.4, 133.4, 134.0, 134.1, 136.4, 137.1, 140.1, 140.3, 170.9, 171.5. HRMS *m/z* Calcd for $C_{21}H_{22}N_2O_2$: 334.1681. Found: 334.1680.

3.3. General procedure for the tandem cyclization–carbonylation-cross-coupling reaction of 2 with 14, 17, and 20

To a THF solution of indolylborate (**2**) generated from indole (**1**) (2 mmol) in situ under an argon atmosphere, **3**, **6**, **9**, **11**, **14**, **17**, or **20** (1 mmol) was added, and the apparatus was filled with carbon monoxide. Palladium complex (0.05 mmol) was placed in a flask, and then carbon monoxide was introduced up to 10 atm. The whole was heated at 60 °C overnight. The mixture was ice-cooled, and 10% NaOH (10 mL) and 30% H_2O_2 (2 mL) were added. After stirring for 10 min, the mixture was diluted with AcOEt (100 mL), washed with brine, and dried over $MgSO_4$. The solvent was removed, and the residue was separated by MPLC with hexane–AcOEt.

3.3.1. 1,3-Dimethyl-3-[2-(1-methyl-1*H*-indol-2-yl)-2-oxoethyl]-1,3-dihydro-2*H*-indol-2-one (23a). Colorless crystals. Mp 145–146 °C (hexane–AcOEt). IR ($CHCl_3$): 1702, 1662, 1612 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.44 (s, 3H), 3.30 (s, 3H), 3.62 (d, 1H, J=17.2 Hz), 3.73 (d, 1H, J=17.2 Hz), 3.81 (s, 3H), 6.87 (d, 1H, J=8.0 Hz), 6.96 (t, 1H, J=7.5 Hz), 7.13 (t, 1H, J=8.0 Hz), 7.17 (d, 1H, J=7.5 Hz), 7.24 (t, 1H, J=7.5 Hz), 7.26–7.31 (m, 2H), 7.37 (t, 1H, J=7.5 Hz), 7.67 (d, 1H, J=8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: 25.1, 26.5, 32.0, 45.7, 46.9, 108.2, 110.3, 111.3, 120.8, 122.1, 122.2, 122.9, 125.7, 126.0, 127.9, 133.6, 134.4, 140.0, 143.8, 180.7, 189.9. MS *m/z*: 332 (M^+). Anal. Calcd for $C_{21}H_{20}N_2O_2$: C, 75.88; H, 6.06; N, 8.43. Found: C, 75.80; H, 6.08; N, 8.29.

3.3.2. *tert*-Butyl 2-[(1,3-dimethyl-2-oxo-2,3-dihydro-1*H*-indol-3-yl)acetyl]-1*H*-indole-1-carboxylate (23b). Colorless crystals. Mp 154–155 °C (hexane–AcOEt). IR ($CHCl_3$): 1706, 1602 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.42 (s, 3H), 1.47 (s, 9H), 3.19 (s, 3H), 3.54 (s, 2H), 6.82 (d, 1H, J=8.0 Hz), 6.89 (s, 1H), 6.96 (t, 1H, J=7.5 Hz), 7.18–7.25 (m, 3H), 7.38 (t, 1H, J=8.0 Hz), 7.55 (d, 1H, J=8.0 Hz), 7.97 (d, 1H, J=8.6 Hz). ^{13}C NMR ($CDCl_3$) δ: 24.7, 26.4, 27.7, 45.6, 48.0, 84.8, 108.1, 114.7, 114.9, 122.3, 122.4, 122.5, 123.3, 127.2, 127.4, 128.0, 133.2, 137.7, 138.4, 143.9, 149.5, 180.1, 189.4. MS *m/z*: 418 (M^+). Anal. Calcd for $C_{25}H_{26}N_2O_4 \cdot 3/10H_2O$: C, 70.84; H, 6.33; N, 6.61. Found: C, 70.94; H, 6.20; N, 6.44.

3.3.3. 2-(1-Acetyl-3-methyl-2,3-dihydro-1*H*-indol-3-yl)-1-(1-methyl-1*H*-indol-2-yl)ethanone (24). Colorless crystals. Mp 91–92 °C (hexane–AcOEt). IR ($CHCl_3$): 1648 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.50 (s, 3H), 2.21 (s, 3H), 3.17 (d, 1H, J=15.8 Hz), 3.46 (d, 1H, J=15.8 Hz), 3.96 (d, 1H, J=11.0 Hz), 4.03 (s, 3H), 4.34 (d, 1H, J=11.0 Hz), 7.05 (t, 1H, J=7.5 Hz), 7.15 (t, 1H, J=6.9 Hz), 7.18–7.27 (m, 3H), 7.34–7.42 (m, 2H), 7.66 (d, 1H, J=8.0 Hz), 8.20 (d, 1H, J=8.0 Hz). ^{13}C NMR ($CDCl_3$) δ: 24.3, 26.4, 32.3, 42.8, 49.2, 61.3, 110.5, 112.1, 117.2, 121.0, 122.2, 123.0, 123.9, 125.7, 126.4, 128.3, 135.2, 139.0, 140.3, 141.7, 168.9, 192.1. MS *m/z*: 346 (M^+). Anal. Calcd for $C_{22}H_{22}N_2O_2$: C, 76.28; H, 6.40; N, 8.09. Found: C, 76.30; H, 6.48; N, 7.98.

3.3.4. 2,4-Dimethyl-4-[2-(1-methyl-1*H*-indol-2-yl)-2-oxoethyl]-3,4-dihydroisoquinolin-1(2*H*)-one (25). Viscous oil. IR ($CHCl_3$): 1642 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.53 (s, 3H), 3.09 (s, 3H), 3.12 (d, 1H, J=14.3 Hz), 3.20 (d, 1H, J=14.3 Hz), 3.52 (d, 1H, J=12.6 Hz), 3.68 (d, 1H, J=12.6 Hz), 4.04 (s, 3H), 7.10 (s, 1H), 7.13 (dt, 1H, J=1.8, 8.0 Hz), 7.31–7.41 (m, 4H), 7.46 (t, 1H, J=7.5 Hz), 7.63 (d, 1H, J=8.0 Hz), 8.12 (d, 1H, J=7.5 Hz). ^{13}C NMR ($CDCl_3$) δ: 23.1, 32.4, 35.1, 37.7, 47.5, 57.2, 110.4, 112.5, 120.9, 123.1, 123.8, 125.6, 126.3, 127.3, 128.3, 128.7, 132.1, 135.6, 140.4, 145.2, 164.6, 192.0. HRMS *m/z* Calcd for $C_{22}H_{22}N_2O_2$: 346.1681. Found: 346.1673.

3.3.5. *N*-Methyl-2-[(1-methyl-1*H*-indol-2-yl)carbonyl]-*N*-(2-methylprop-2-en-1-yl)benzamide (26). Viscous oil. IR (neat): 1632 cm^{-1}. ^1H NMR ($CDCl_3$) δ: 1.63 and 1.67 (two s, 3H), 2.86 and 2.92 (two s, 3H), 3.76 (s, 1H), 4.03 (s, 1H), 4.10 (s, 3H), 4.87 (s, 1H), 4.90 and 4.94 (two s, 1H), 6.95 (d, 1H, J=4.6 Hz), 7.10–7.16 (m, 1H), 7.35–7.58 (m, 5H), 7.60–7.64 (m, 1H), 7.73 (d, 1H, J=7.5 Hz). ^{13}C NMR ($CDCl_3$) δ: 19.9, 20.1, 32.0, 32.6, 36.3, 52.7, 53.5, 57.3, 110.3, 112.5, 112.9, 115.7, 115.8, 120.8, 123.2, 125.9, 126.2, 126.3, 126.7, 127.2, 128.2, 128.3, 129.9, 130.1, 130.8, 135.1, 137.6, 137.9, 138.2, 138.5, 140.5, 140.6, 170.6, 171.3, 188.4, 188.5. HRMS *m/z* Calcd for $C_{22}H_{22}N_2O_2$: 346.1681. Found: 346.1677.

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References and notes

1. (a) Diederich, F.; Stang, P. J. *Metal-catalyzed Cross-coupling Reactions*; Wiley-VCH: Weinheim, 1998; (b) Prim, D.; Campage, J. M.; Joseph, D.; Andrioletti, B. *Tetrahedron* **2002**, *58*, 2041–2075; (c) Chinchilla, R.; Najera, C.; Yus, M. *Chem. Rev.* **2004**, *104*, 2667–2722.
2. (a) Grigg, R. *J. Heterocycl. Chem.* **1994**, *31*, 631–639; (b) Grigg, R.; Sridharan, V. *Comprehensive Organometallic Chemistry II*; Abel, E. W., Stone, F. G. A., Wilkinson, G., Eds.; Pergamon: Oxford, 1995; Vol. 12, pp 299–321.
3. Suzuki, A.; Brown, H. C. *Organic Syntheses via Boranes*; Aldrich Chemical: Milwaukee, WI, 2003; Vol. 3.
4. (a) Couty, S.; Liegault, B.; Meyer, C.; Cossy, J. *Org. Lett.* **2004**, *6*, 2511–2514; (b) Yanada, R.; Obika, S.; Inokuma, T.; Yanada, K.; Yamashita, M.; Ohta, S.; Takemoto, Y. *J. Org. Chem.* **2005**, *70*, 6972–6975; (c) Cheung, W. S.; Patch, R. J.; Player, M. R. *J. Org. Chem.* **2005**, *70*, 3741–3744.
5. (a) Burns, B.; Grigg, R.; Sridharan, V.; Stevenson, P.; Worakun, T. *Tetrahedron Lett.* **1989**, *30*, 1135–1138; (b) Negishi, E.; Noda, Y.; Lamaty, F.; Vawter, E. J. *Tetrahedron Lett.* **1990**, *31*, 4393–4396; (c) Grigg, R.; Redpath, J.; Sridharan, V.; Wilson, D. *Tetrahedron Lett.* **1994**, *35*, 4429–4432; (d) Grigg, R.; Sandano, J. M.; Santhakumar, V.; Sridharan, V.; Thangavelanthum, R.; Thompton-Pett, M.; Wilson, D. *Tetrahedron* **1997**, *53*, 11803–11826.
6. Ishikura, M. *Curr. Org. Chem.* **2002**, *6*, 507–521.
7. Ishikura, M.; Terashima, M. *J. Chem. Soc., Chem. Commun.* **1989**, 135–136.
8. Ishikura, M. *J. Chem. Soc., Chem. Commun.* **1995**, 409–410.
9. Ishikura, M.; Agata, I.; Katagiri, N. *J. Heterocycl. Chem.* **1999**, *36*, 873–879.
10. (a) Ozawa, F.; Sugimoto, T.; Yuasa, M.; Yamamoto, T.; Yamamoto, A. *Organometallics* **1984**, *3*, 683–692; (b) Huang, L.; Ozawa, F.; Yamamoto, A. *Organometallics* **1990**, *9*, 2603–2611.
11. Wang, R. T.; Chou, F. L.; Luo, F. T. *J. Org. Chem.* **1990**, *55*, 4846–4849.
12. (a) Collman, J. P.; Hegedus, L. S.; Norton, J. R.; Finke, R. G. *Principles and Applications of Organotransition Metal Chemistry*; University Science Books: Mill Valley, CA, 1987; (b) Cornils, B.; Hermann, W. A. *Applied Homogeneous Catalysis with Organometallic Compounds*; Wiley: Weinheim, 1999; (c) Tsuji, J. *Transition Metal Reagents and Catalysts: Innovations in Organic Synthesis*; Wiley: Chichester, UK, 2000.
13. Canty, A. J. *Comprehensive Organometallic Chemistry II*; Abel, E. W., Stone, F. G. A., Wilkinson, G., Eds.; Pergamon: Oxford, 1995; Vol. 9, pp 225–290.
14. Ishikura, M.; Matsuzaki, Y.; Agata, I.; Katagiri, N. *Tetrahedron* **1998**, *54*, 13929–13942.
15. Shaughnessy, K. H.; Hamann, B. C.; Hartwig, J. F. *J. Org. Chem.* **1998**, *63*, 6546–6553.
16. Ishikura, M.; Terashima, M. *J. Org. Chem.* **1994**, *59*, 2634–2637.