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Access to fused pyrroles via the reaction of spiro-dienyl ethers with amines involving a chemoselective skeletal rearrangement

Xiaoyu Zhang [a], Li Huang [a], Hui Peng [a], Fanghua Ji [a], Xuehui Li [a], Biaolin Yin [a,b,*]

[a] School of Chemistry and Chemical Engineering, South China University of Technology, Guangzhou 510640, Guangdong, China
[b] State Key Laboratory of Pulp and Paper Engineering, South China University of Technology, Guangzhou 510640, China

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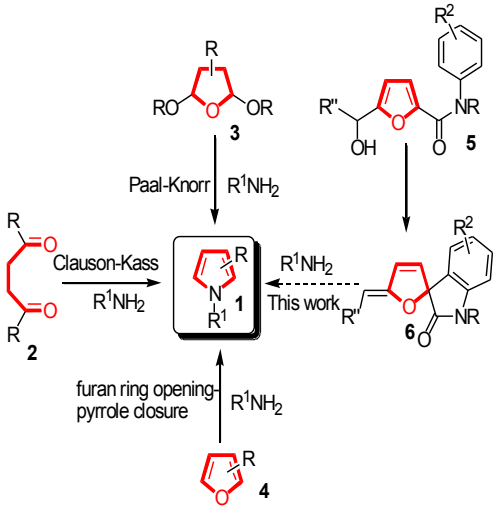
ABSTRACT

Under metal-free conditions, the reaction of spiro-dienyl ethers, derived from furan derivatives, with aromatic amines provided fused pyrroles. The reaction proceeded through an interesting and chemoselective skeletal rearrangement and provided an alternative protocol for the construction of pyrrole rings from furan derivatives.

1. Introduction

Pyrrole derivatives **1** are prevalent in a wide variety of biologically and medicinally important compounds[1] and used as building blocks for the construction of pharmaceutical agents[2] and electronic materials.[3] Consequently, numerous methods for their synthesis have been developed over the years, including the Knorr reaction,[4] Hantzsch reaction,[5] Clauson-Kass reaction,[6] Paal–Knorr reaction,[4c,7] transition-metal-mediated reaction,[8] and other operations.[9] Among these methods, the Paal–Knorr and Clauson-Kass reactions are the most commonly used, albeit multi-step synthetic operations are required. A similar protocol based on the furan ring opening-pyrrole closure strategy is also extensively used (Scheme 1).[10] Due to the fact that furan derivatives have attracted great attentions as green, renewable building blocks in organic synthesis,[11] it is highly desirable to develop access to structurally novel pyrroles starting from furan derivatives.



Scheme 1. Strategy to synthesize pyrroles from furan or its derivatives.

2. Results and discussion

Acid-catalyzed rearrangement of suitable 2-furylcarbinols **7** into 4-hydroxycyclopentenone derivatives **8** (namely Piancatelli rearrangement)[12] has been well used as a key step in the construction of a series of natural products and biologically relevant cyclopentenones.[13] The overall transformation is considered to proceed through a cascade sequence that terminates with a 4π-electrocyclic ring closure of a pentadienyl cation (Scheme 2). Recently we and other groups explored the Piancatelli rearrangement in an intramolecular fashion and developed an access to spiro-compounds.[14] More recently, we disclosed an approach to a class of spiro-dienyl ethers **6** from 2-furylcarbinol **5** and explored

* Corresponding author. E-mail address: blyin@scut.edu.cn (B. Yin).

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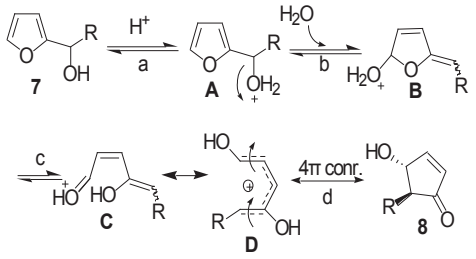
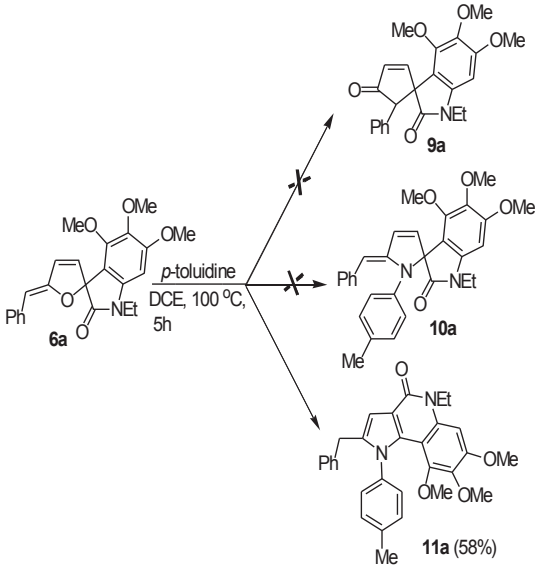


Scheme 2. Proposed mechanism of the Piancatelli reaction. conr.=conrotatory.

the thermal rearrangement of **6** into cyclopentenone.[15] Given that the highly strained **6** is readily synthesized from furans and it contains multiple reactive sites, it is anticipated that further modification of the spiro-dienyl enol segment of **6** would provide access to a variety of structurally novel heterocycles and thus expand the synthetic application of sustainable material from furan derivatives.

Owing to the importance of spirooxindoles **10a** bearing a 2,5-dihydro-pyrrole subunit in medicinal significance, we attempted to synthesize **10a** via the reaction of **6a** in the presence of *p*-toluidine, assuming that the thermal rearrangement of **6a** into **9a** could be suppressed. However, upon heating **6a** with 4-methylaniline in DCE at 100 °C for 5 h, no expected spirooxindoles **10a** was produced. Instead, a fused pyrrole **11a** was formed in 58% yield (Scheme 3). The structure of **11a** was unambiguously determined by X-ray crystallography (Fig. 1).[16] This unexpected result nonetheless provided an unprecedented access to fused pyrroles with structural novelty from dienyl ether. The reaction of dienyl ether with nucleophiles, such as amine, has never been reported. Exploring such a reaction would expand the synthetic applications of furan derivatives.



Scheme 3. The reaction of **6a** with *p*-toluidine.

We then screened a variety of catalysts, solvents, and reaction temperatures to optimize the reaction as shown in Table 1. The reaction outcome was greatly influenced by the temperature. For instance, lowering the reaction temperature to 80 °C shut down the reaction completely (entry 2). In contrast, a slight increase of temperature to 105 °C enhanced the yield to 65% (entry 3). Further

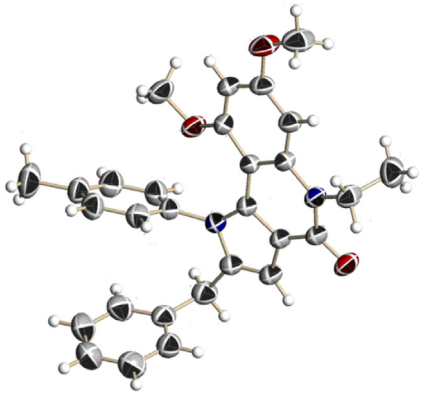
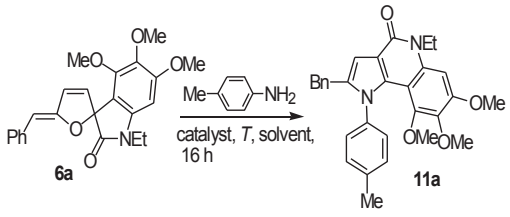


Fig. 1. X-ray crystal structure of compound **11n**.

Table 1
Optimization of the reaction conditions[a]



Entry	Catalyst	*T* (°C)	Solvent	Yield (%)[b]
1	—	100	DCE	58
2	—	80	DCE	0
3	—	105	DCE	65
4	—	110	DCE	50
5	—	130	DCE	15
6	—	105	Toluene	ND
7	—	105	DMF	ND
8	—	105	Dioxane	54
9	—	105	THF	59
10	CSA	105	DCE	66
11	$ZnCl_2$	105	DCE	75
12	**p-TsOH**	**105**	**DCE**	**84**
13	MS 4 Å	105	DCE	80

Bold values signify optimized reaction conditions.

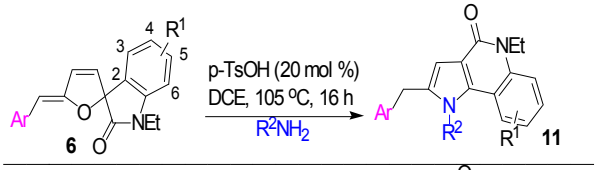
[a] All reactions were performed on a 0.3 mmol scale. Unless otherwise noted, the amount of the catalyst was 20 mol %. ND: not detected. NR: no reaction.

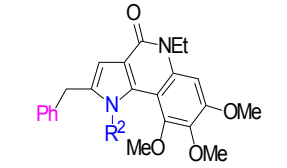
[b] Isolated yield.

increasing the temperature to 110 °C lowered the yield to 50% (entry 4), accompanied by a small amount of rearranged product **9a**, which could be isolated in 62% yield when conducting the reaction at 130 °C, and the yield of **11a** decreased to 15% (entry 5). After screening a wide range of solvents, DCE was turned out to be the best (entries 6–9). Several catalysts, such as CSA, $ZnCl_2$, *p*-TsOH, and molecular sieves 4 Å, were examined (entries 10–13) and *p*-TsOH (20 mol %) provided the best yield (84%, entry 11). Therefore, the optimized combination for this reaction was to use DCE as the solvent, *p*-TsOH (20 mol %) as the catalyst, and 105 °C as the reaction temperature.

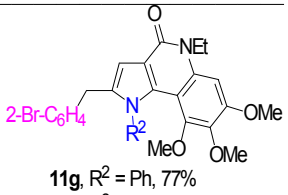
With our optimized reaction conditions, a range of R^2NH_2 with different **6** containing various Ar and R^1 group were tested to investigate the reaction scope as demonstrated in Table 2. The amine structure was critical to the success of this reaction. When R^2 was aromatic, the reaction proceeded well, giving the desired **11** in moderate-to-good yields. In contrast, no desired product was produced when R^2 was an alkyl group (**11f**). Complicated reaction mixtures were obtained, when using phenylhydrazine as the amine, and the yields were lower (**11e** and **11r**). It is worth

Table 2
Synthesis of **11**[a,b]

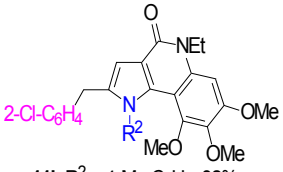




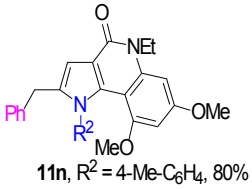
11a, R^2 = 4-Me-C_6H_4, 82%
11b, R^2 = 3-MeO-C_6H_4, 75%
11c, R^2 = 3,5-di-MeO-C_6H_3, 65%
11d, R^2 = 3-Me-C_6H_4, 82%
11e, R^2 = PhNH, 45%
11f, R^2 = Bn, 0%



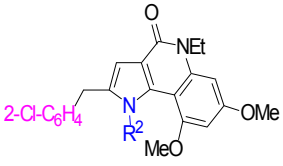
11g, R^2 = Ph, 77%
11h, R^2 = 4-Me-C_6H_4, 80%
11i, R^2 = 3-MeO-C_6H_4, 74%
11j, R^2 = 3,5-di-MeO-C_6H_3, 60%
11k, R^2 = 4-NO_2-C_6H_4, 81%



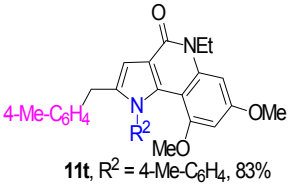
11l, R^2 = 4-Me-C_6H_4, 82%
11m, R^2 = 3-MeO-C_6H_4, 77%



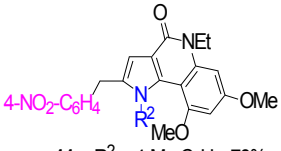
11n, R^2 = 4-Me-C_6H_4, 80%



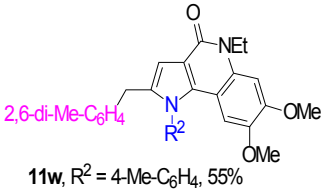
11o, R^2 = Ph, 66%
11p, R^2 = 4-Me-C_6H_4, 80%
11q, R^2 = 3-Me-C_6H_4, 72%
11r, R^2 = PhNH, 48%
11s, R^2 = 3,5-di-Me-C_6H_3, 62%



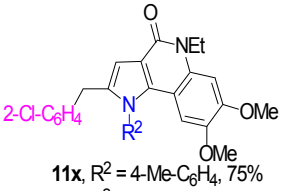
11t, R^2 = 4-Me-C_6H_4, 83%



11u, R^2 = 4-Me-C_6H_4, 78%
11v, R^2 = H, 73%



11w, R^2 = 4-Me-C_6H_4, 55%



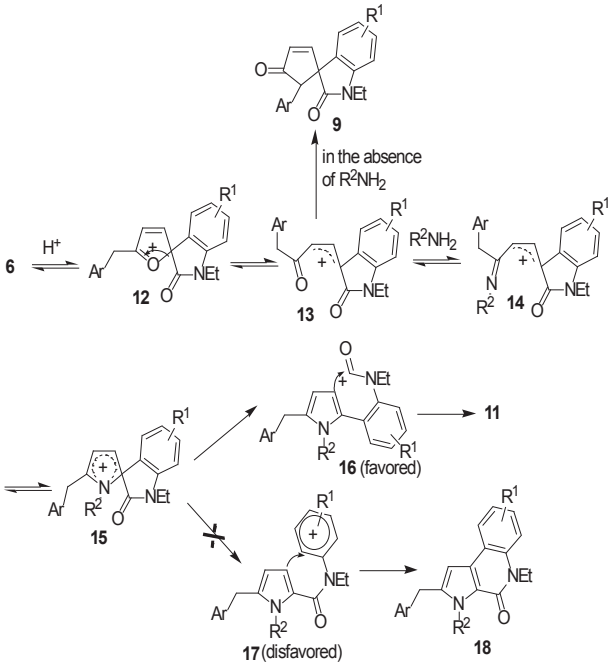
11x, R^2 = 4-Me-C_6H_4, 75%
11y, R^2 = PhCONH, 0%
11z, R^2 = HCONH, 0%

[a]All reactions were performed on a 0.3-mmol scale.

[b]Isolated yield.

highlighting that when $NH_3 \cdot H_2O$ was used as the nucleophile, the desired product was produced in good yield (**11v**). Notably, due to their weak nucleophilicity, benzoyl amide, and formamide as the nucleophiles resulted in no reaction (**11y** and **11z**). The electronic properties of the substituents on the Ar rings did not apparently influence the reaction.

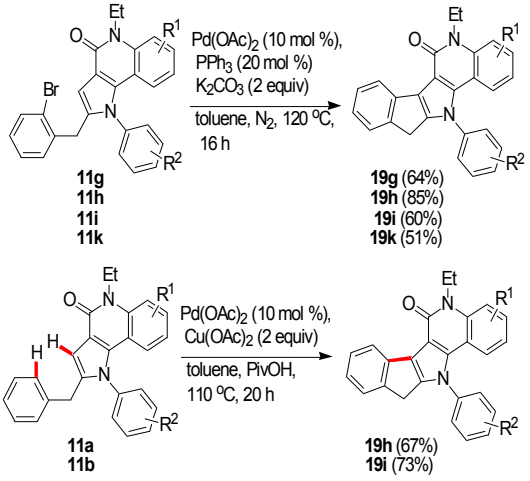
On the basis of the experimental results shown above, a tentative mechanistic interpretation is proposed in Scheme 4. Protonation of **6** gave oxocarbonium ion **12**, which would then undergo the ring-opening process to provide the intermediate **13**. The condensation of **13** with R^3NH_2 gave the intermediate **14**. An electro-cyclization is preceded to give the intermediate **15**, which



Scheme 4. A plausible reaction mechanism.

then undergoes two possible types of heterolytic C–C bond cleavage to give open chain intermediate **16** or **17**. According to the observation, the formation of **16** is favored over intermediate **17**, presumably because the formation of phenyl carbocation is more difficulty than the aminoacylium cation. An intramolecular acylation of pyrrole at C-3 from **16** generates the product **11**. In the absence of amines, the reaction would undergo a rearrangement to generate product **9** straightly from intermediate **13**.

To further demonstrate the synthetic utility of this protocol, tricyclic pyrroles **11** were transformed to pentacyclic pyrroles **19g**–**i** and **19k** in moderate-to-good yields via two notable approaches: either the Pd-catalyzed intramolecular direct arylation of the pyrrole ring at its β-position or a regio-selective intramolecular dehydrogenative coupling reaction using $Cu(OAc)_2$ as the oxidant. Both two approaches led to the products in good yields (Scheme 5).



Scheme 5. Synthesis of pentacyclic pyrroles **19**.

3. Conclusion

In summary, we have developed a novel access to fused pyrroles via the unprecedented reaction of dienyl ethers derived from furans with amines under metal-free conditions. We have disclosed for the first time that the thermal rearrangement of dienyl ether into cyclopentenone can be suppressed in the presence of suitable nucleophiles, such as amine, under suitable conditions. The involved mechanism of dienone–phenol-like rearrangement is also interesting and may open a new avenue to further design new reactions, owing to the ready availability of dienyl ethers from furans.

4. Experimental section

4.1. General

IR spectra were recorded with FTIR as a thin film or using KBr pellets and are expressed in cm^{-1}. ^1H (400 MHz) and ^{13}C (100 MHz) NMR spectra were recorded using $CDCl_3$ as a solvent. Chemical shifts are reported in parts per million downfield to tetramethylsilane. Coupling constants are reported and expressed in Hertz; splitting patterns are designated as s (singlet), d (doublet), t (triplet), q (quartet), m (multiplet), dd (double doublet), dt (double triplet), dq (double quartet). Infrared (IR) spectra were obtained on a Bruker Vector 22 spectrometer. Mass spectra were obtained from high resolution ESI mass spectrometer. All reactions were carried out using freshly distilled and dry solvents. Column chromatography was performed over silica gel (100–200 mesh) using petroleum ether and ethyl acetate as the eluent.

4.2. General procedure for the synthesis of 11 from 6

The mixture of **6** (0.3 mmol), amine (0.3 mmol), DCE (5 mL), and *p*-TsOH (10.3 mg, 0.06 mmol) was stirred at 105 °C under nitrogen atmosphere for ~16 h. After the disappearance of material **6** according to TLC, the mixture was cooled to room temperature. Removal of the organic solvent provided the crude product, which then was purified by flash chromatography on silica gel (eluent: EtOAc/PE=1:3) to give **11**.

*4.2.1. 2-Benzyl-5-ethyl-7,8,9-trimethoxy-1-(p-tolyl)-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11a**).* Brown solid (118 mg, 82%), mp=157–159 °C; IR (film) 2927, 1645, 1509, 1453, 1252, 755 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.23–7.18 (m, 3H), 7.12 (d, J=8.0 Hz, 2H), 7.04–7.02 (m, 2H), 6.91 (d, J=8.0 Hz, 2H), 6.69 (s, 1H), 6.67 (s, 1H), 4.45 (q, J=7.2 Hz, 2H), 3.94 (s, 3H), 3.75 (s, 2H), 3.64 (s, 3H), 3.20 (s, 3H), 2.39 (s, 3H), 1.41 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.3, 152.7, 148.4, 140.1, 139.7, 138.7, 137.0, 136.8, 134.1, 134.0, 129.1, 128.8, 128.6, 128.2, 126.2, 126.1, 116.3, 106.3, 94.1, 61.0, 59.9, 56.0, 37.4, 34.4, 21.1, 12.9; Ion-trap-HRMS (ESI) calcd for $C_{30}H_{31}N_2O_4$ $[M+H]^+$ 483.2284, found 483.2270.

*4.2.2. 2-Benzyl-5-ethyl-7,8,9-trimethoxy-1-(3-methoxyphenyl)-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11b**).* Brown solid (112 mg, 75%), mp=124–126 °C; IR (KBr) 2927, 1645, 1456, 1325, 1256, 755 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.24–7.14 (m, 4H), 7.04–7.02 (m, 2H), 6.87–6.85 (m, 1H), 6.72 (s, 1H), 6.69 (s, 1H), 6.68–6.66 (m, 1H), 6.51–6.50 (m, 1H), 4.46 (q, J=7.2 Hz, 2H), 3.95 (s, 3H), 3.80 (d, J=16 Hz, 2H), 3.64 (s, 3H), 3.63 (s, 3H), 3.23 (s, 3H), 1.42 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.8, 159.3, 152.8, 148.3, 143.3, 139.7, 138.7, 137.0, 134.1, 133.9, 129.1, 128.7, 128.3, 126.2, 118.9, 116.3, 113.3, 112.0, 106.6, 103.8, 94.0, 61.0, 60.0, 56.0, 55.3, 37.4, 34.4, 12.9; Ion-trap-HRMS (ESI) calcd for $C_{30}H_{31}N_2O_5$ $[M+H]^+$ 499.2233, found 499.2246.

*4.2.3. 2-Benzyl-1-(3,5-dimethoxyphenyl)-5-ethyl-7,8,9-trimethoxy-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11c**).* Yellow solid (105 mg, 65%), mp=101–103 °C; IR (KBr) 2926, 1608, 1480, 1286, 755 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.19–7.13 (m, 2H), 7.10–7.07 (m, 1H), 6.99–6.97 (m, 2H), 6.65–6.62 (m, 2H), 6.35 (s, 1H), 6.10 (s, 2H), 4.38 (q, J=7.2 Hz, 2H), 3.88 (s, 3H), 3.77 (s, 2H), 3.59 (s, 3H), 3.55 (s, 3H), 3.22 (s, 3H), 1.35 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.6, 159.3, 152.8, 148.4, 143.7, 139.5, 138.9, 137.0, 134.1, 133.9, 128.7, 128.3, 126.2, 116.3, 106.6, 105.0, 103.8, 99.7, 94.0, 89.3, 61.0, 60.2, 56.0, 55.4, 37.4, 34.4, 12.9; Ion-trap-HRMS (ESI) calcd for $C_{31}H_{33}N_2O_6$ $[M+H]^+$ 529.2339, found 529.2353.

*4.2.4. 2-Benzyl-5-ethyl-7,8,9-trimethoxy-1-(m-tolyl)-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11d**).* Brown syrup (114 mg, 82%): IR (KBr) 2924, 1644, 1505, 1252, 1256, 754 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.22–7.16 (m, 5H), 7.11 (d, J=7.6 Hz, 1H), 7.02–7.01 (m, 2H), 6.87 (d, J=7.6 Hz, 1H), 6.71 (s, 1H), 6.69 (s, 1H), 4.46 (q, J=7.2 Hz, 2H), 3.95 (s, 3H), 3.74 (s, 2H), 3.62 (s, 3H), 3.17 (s, 3H), 2.27 (s, 3H), 1.42 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.3, 152.8, 148.3, 142.1, 139.8, 138.7, 138.4, 137.0, 134.1, 133.9, 128.8, 128.3, 128.2, 127.8, 127.2, 126.1, 123.4, 116.4, 106.4, 103.8, 94.0, 60.9, 59.8, 56.0, 37.4, 34.5, 21.1, 12.9; Ion-trap-HRMS (ESI) calcd for $C_{30}H_{31}N_2O_4$ $[M+H]^+$ 483.2284, found 483.2269.

*4.2.5. 2-Benzyl-5-ethyl-7,8,9-trimethoxy-1-(phenylamino)-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11e**).* Yellow solid (65 mg, 45%), mp=94–96 °C; IR (KBr) 3446, 2923, 1642, 1456, 1267, 754 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.34–7.31 (m, 3H), 7.22–7.16 (m, 3H), 7.04–7.00 (m, 4H), 6.70 (s, 1H), 6.69 (s, 1H), 4.46 (q, J=7.2 Hz, 2H), 3.94 (s, 3H), 3.78 (s, 2H), 3.61 (s, 3H), 3.18 (s, 3H), 1.42 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.3, 152.8, 148.3, 142.3, 139.8, 138.6, 137.1, 134.1, 134.0, 128.7, 128.5, 128.2, 127.1, 126.4, 126.2, 116.4, 106.5, 103.8, 94.1, 60.9, 59.8, 56.0, 37.4, 34.4, 12.9; Ion-trap-HRMS (ESI) calcd for $C_{29}H_{30}N_3O_4$ $[M+H]^+$ 484.2236, found 484.2249.

*4.2.6. 2-(2-Bromo-benzyl)-5-ethyl-7,8,9-trimethoxy-1-phenyl-1,5-dihydro-pyrrolo[3,2-c]quinolin-4-one (**11g**).* Brown solid (126 mg, 77%), mp=246–248 °C; IR (KBr) 2932, 1645, 1554, 1458, 1277, 1023, 754 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.53 (dd, J=0.8 Hz, J=8.0 Hz, 1H), 7.23–7.08 (m, 3H), 7.05 (br, 1H), 7.03–6.99 (m, 4H), 6.72 (s, 1H), 6.51 (s, 1H), 4.46 (q, J=7.2 Hz, 1H), 3.98 (s, 3H), 3.84 (s, 2H), 3.68 (s, 3H), 2.42 (s, 3H), 1.44 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.3, 152.9, 148.4, 139.1, 138.7, 138.3, 137.1, 136.9, 134.2, 134.1, 132.8, 131.0, 129.3, 128.2, 127.4, 126.0, 124.7, 116.4, 106.5, 103.9, 94.1, 61.0, 59.9, 56.1, 37.4, 35.0, 21.2, 12.9; Ion-trap-HRMS (ESI) calcd for $C_{29}H_{28}BrN_2O_4$ $[M+H]^+$ 547.1232, found 547.1259.

*4.2.7. 2-(2-Bromo-benzyl)-5-ethyl-7,8,9-trimethoxy-1-p-tolyl-1,5-dihydro-pyrrolo[3,2-c]quinolin-4-one (**11h**).* Yellow solid (134 mg, 80%), mp=255–257 °C; IR (KBr) 2930, 1621, 1545, 1447, 1257, 1024, 752 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.54 (dd, J=1.2 Hz, J=7.6 Hz, 1H), 7.27–7.08 (m, 5H), 7.03 (br, 1H), 7.00 (br, 1H), 6.72 (s, 1H), 6.51 (s, 1H), 4.47 (q, J=7.6 Hz, 2H), 3.98 (s, 3H), 3.94 (s, 2H), 3.68 (s, 3H), 3.24 (s, 3H), 2.42 (s, 3H), 1.44 (t, J=7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.5, 152.9, 148.9, 140.0, 138.5, 138.4, 137.1, 137.0, 134.1, 133.9, 132.5, 130.9, 129.3, 127.9, 127.2, 125.9, 124.4, 116.1, 106.3, 103.7, 94.3, 60.8, 56.1, 37.4, 35.0, 21.0, 12.9; Ion-trap-HRMS (ESI) calcd for $C_{30}H_{30}BrN_2O_4$ $[M+H]^+$ 561.1389, found 561.1374.

*4.2.8. 2-(2-Bromo-benzyl)-5-ethyl-7,8,9-trimethoxy-1-(3-methoxyphenyl)-1,5-dihydro-pyrrolo[3,2-c]quinolin-4-one (**11i**).* Brown solid (128 mg, 74%), mp=298–300 °C; IR (KBr) 2921, 1630, 1528, 1430, 1241, 1038, 754 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.50 (d, J=8.0 Hz,

1H), 7.28–7.60 (m, 4H), 6.88 (dd, *J*=8.4 Hz, 1H), 6.71 (br, 1H), 6.70 (br, 1H), 6.62 (br, 1H), 6.55 (br, 1H), 4.45 (q, *J*=6.8 Hz, 2H), 3.96 (s, 3H), 3.71 (s, 3H), 3.66 (s, 3H), 3.25 (s, 3H), 1.42 (t, *J*=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.0, 159.3, 153.0, 148.4, 143.3, 138.3, 137.1, 134.2, 134.0, 132.8, 130.9, 129.4, 128.2, 127.4, 124.6, 118.8, 116.5, 11.3, 116.9, 113.3, 111.9, 106.8, 103.8, 94.1, 61.0, 60.0, 56.1, 55.4, 37.5, 34.9, 12.9; Ion-trap-HRMS (ESI) calcd for $C_{30}H_{30}BrN_2O_5$ $[M+H]^+$ 577.1388, found 577.1362.

*4.2.9. 2-(2-Bromo-benzyl)-1-(3,5-dimethoxy-phenyl)-5-ethyl-7,8,9-trimethoxy-1,5-dihydro-pyrrolo[3,2-c]quinolin-4-one (**11j**).* Brown solid (109 mg, 60%), mp=294–296 °C; IR (KBr) 2918, 1635, 1523, 1442, 1235, 1039, 755 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43 (d, *J*=7.6 Hz, 2H), 7.15–6.98 (m, 3H), 6.62 (s, 1H), 6.50 (s, 1H), 6.36 (t, *J*=2.4 Hz, 1H), 6.16 (d, *J*=2.0 Hz, 2H), 4.37 (q, *J*=7.2 Hz, 2H), 3.88 (s, 3H), 3.84 (s, 2H), 3.60 (s, 3H), 3.59 (s, 6H), 3.24 (s, 3H), 1.36 (t, *J*=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 161.0, 159.5, 152.9, 148.5, 143.9, 138.7, 138.2, 137.1, 134.3, 134.2, 132.7, 130.9, 128.2, 127.4, 124.6, 116.4, 106.9, 104.9, 103.8, 99.8, 97.1, 94.3, 60.9, 60.0, 55.9, 55.5, 37.5, 35.1, 12.9; Ion-trap-HRMS (ESI) calcd for $C_{31}H_{32}BrN_2O_6$ $[M+H]^+$ 607.1444, found 607.1495.

*4.2.10. 2-(2-Bromo-benzyl)-5-ethyl-7,8,9-trimethoxy-1-(4-nitro-phenyl)-1,5-dihydro-pyrrolo[3,2-c]quinolin-4-one (**11k**).* Brown solid (144 mg, 81%), mp=315–317 °C; IR (KBr) 2922, 1625, 1538, 1450, 1241, 1045, 756 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.23 (d, *J*=8.8 Hz, 2H), 7.49 (d, *J*=7.6 Hz, 1H), 7.24 (d, *J*=8.8 Hz, 3H), 7.19 (d, *J*=6.8 Hz, 2H), 7.09 (d, *J*=7.6 Hz, 1H), 6.73 (s, 1H), 6.64 (s, 1H), 4.46 (q, *J*=7.2 Hz, 2H), 3.97 (s, 3H), 3.90 (s, 2H), 3.64 (s, 3H), 3.28 (s, 3H), 1.43 (t, *J*=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.3, 159.0, 153.5, 147.9, 147.7, 146.5, 137.8, 137.4, 134.3, 134.2, 132.9, 130.6, 128.5, 128.7, 126.7, 134.4, 134.2, 117.3, 108.1, 103.3, 94.6, 61.2, 60.1, 56.1, 37.6, 34.6, 12.9; Ion-trap-HRMS (ESI) calcd for $C_{29}H_{27}BrN_3O_6$ $[M+H]^+$ 592.1083, found 592.1067.

*4.2.11. 2-(2-Chlorobenzyl)-5-ethyl-7,8,9-trimethoxy-1-(p-tolyl)-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11l**).* Yellow solid (118 mg, 82%), mp=164–166 °C; IR (KBr) 2924, 1647, 1456, 1263, 755 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.31–7.29 (m, 1H), 7.16–7.11 (m, 5H), 6.98–6.97 (m, 2H), 6.69 (s, 1H), 6.50 (s, 1H), 4.42 (d, *J*=7.2 Hz, 2H), 3.94 (s, 3H), 3.81 (s, 2H), 3.64 (s, 3H), 3.21 (s, 3H), 2.38 (s, 3H), 1.40 (t, *J*=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.2, 152.8, 148.4, 139.7, 138.6, 137.0, 136.9, 136.5, 134.1, 134.0, 134.0, 130.9, 129.4, 129.3, 127.9, 126.7, 125.9, 116.3, 106.3, 103.9, 94.1, 61.0, 59.9, 56.0, 37.4, 32.2, 21.1, 12.9; Ion-trap-HRMS (ESI) calcd for $C_{30}H_{30}ClN_2O_4$ $[M+H]^+$ 517.1894, found 517.1906.

*4.2.12. 2-(2-Chlorobenzyl)-5-ethyl-7,8,9-trimethoxy-1-(3-methoxyphenyl)-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11m**).* Brown solid (123 mg, 77%), mp=182–184 °C; IR (KBr) 2926, 1646, 1457, 1263, 1098, 755 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32–7.30 (m, 2H), 7.16–7.10 (m, 3H), 6.89–6.86 (m, 1H), 6.71 (s, 1H), 6.69 (s, 1H), 6.61 (s, 1H), 6.59 (s, 1H), 4.45 (q, *J*=7.2 Hz, 2H), 3.95 (s, 3H), 3.88–3.87 (br, 2H), 3.68 (s, 3H), 3.65 (s, 3H), 3.25 (s, 3H), 1.42 (t, *J*=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.9, 159.2, 152.9, 148.3, 143.2, 138.2, 137.0, 136.5, 134.1, 134.0, 133.9, 130.8, 129.3, 127.9, 126.8, 118.7, 116.4, 113.2, 111.8, 106.6, 103.7, 94.0, 61.0, 60.0, 56.0, 55.3, 37.4, 32.1, 12.9; Ion-trap-HRMS (ESI) calcd for $C_{30}H_{30}ClN_2O_5$ $[M+H]^+$ 533.1843, found 533.1857.

*4.2.13. 2-Benzyl-5-ethyl-7,9-dimethoxy-1-(p-tolyl)-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11n**).* Yellow solid (108 mg, 80%), mp=107–109 °C; IR (KBr) 2925, 1644, 1454, 1208, 753 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.20–7.16 (m, 3H), 7.14 (d, *J*=8.0 Hz, 2H), 7.02–7.01 (m, 2H), 6.89 (d, *J*=8.0 Hz, 2H), 6.67 (s, 1H), 6.55 (s, 1H), 6.06 (s, 1H), 4.43 (q, *J*=7.2 Hz, 2H), 3.85 (s, 3H), 3.73 (s, 2H), 2.94 (s, 3H), 2.39 (s, 3H), 1.39 (t, *J*=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.7, 159.5, 155.2, 140.3, 139.4, 139.3, 138.8, 136.5, 134.7, 128.9, 128.8, 128.2, 126.4, 126.1, 115.5, 106.1, 100.3, 92.1, 91.6, 55.3, 53.8, 37.5, 34.4, 21.1, 12.9; Ion-trap-HRMS (ESI) calcd for $C_{29}H_{29}N_2O_3$ $[M+H]^+$ 453.2178, found 453.2159.

*4.2.14. 2-(2-Chlorobenzyl)-5-ethyl-7,9-dimethoxy-1-phenyl-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11o**).* Brown solid (93 mg, 66%), mp=152–153 °C; IR (KBr) 2923, 1645, 1456, 1254, 755 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39–7.28 (m, 4H), 7.15–7.07 (m, 5H), 6.56 (s, 1H), 6.55 (s, 1H), 6.07 (s, 1H), 4.43 (d, *J*=7.2 Hz, 2H), 3.86 (s, 3H), 3.81 (s, 2H), 2.99 (s, 3H), 1.39 (t, *J*=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.6, 159.6, 155.2, 142.8, 139.3, 137.7, 136.5, 134.7, 133.9, 130.9, 129.3, 128.6, 127.8, 126.9, 126.7, 126.5, 115.7, 106.4, 100.2, 92.2, 91.6, 55.3, 53.8, 37.6, 32.0, 12.8; Ion-trap-HRMS (ESI) calcd for $C_{28}H_{26}N_2O_3$ $[M+H]^+$ 473.1632, found 473.1644.

*4.2.15. 2-(2-Chlorobenzyl)-5-ethyl-7,9-dimethoxy-1-(p-tolyl)-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11p**).* Brown solid (117 mg, 80%), mp=161–163 °C; IR (KBr) 2924, 1644, 1457, 1263, 1080, 755 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.31–7.28 (m, 1H), 7.18–7.11 (m, 5H), 6.97–6.95 (m, 2H), 6.55 (s, 1H), 6.50 (s, 1H), 6.08 (s, 1H), 4.42 (q, *J*=7.2 Hz, 2H), 3.86 (s, 3H), 3.79 (s, 2H), 2.96 (s, 3H), 2.39 (s, 3H), 1.39 (t, *J*=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.6, 159.6, 155.2, 140.3, 139.3, 137.8, 136.6, 134.7, 134.0, 131.0, 129.3, 129.1, 127.8, 126.7, 126.2, 115.5, 106.1, 100.3, 92.1, 91.6, 55.3, 53.8, 37.5, 32.1, 21.0, 12.8; Ion-trap-HRMS (ESI) calcd for $C_{29}H_{28}ClN_2O_3$ $[M+H]^+$ 487.1788, found 487.1769.

*4.2.16. 2-(2-Chlorobenzyl)-5-ethyl-7,9-dimethoxy-1-(m-tolyl)-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11q**).* Brown solid (105 mg, 72%), mp=136–137 °C; IR (KBr) 2923, 1639, 1459, 1266, 1080, 755 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32–7.28 (m, 1H), 7.24–7.22 (m, 2H), 7.14–7.09 (m, 4H), 6.84 (s, 1H), 6.58 (s, 1H), 6.56 (s, 1H), 6.08 (s, 1H), 4.44 (q, *J*=7.2 Hz, 2H), 3.86 (s, 3H), 3.82 (s, 2H), 2.93 (s, 3H), 2.31 (s, 3H), 1.40 (t, *J*=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.6, 159.6, 155.2, 139.3, 138.5, 137.7, 136.6, 130.9, 130.1, 129.3, 129.3,128.8, 128.3, 127.7, 127.6, 127.5, 127.1, 126.7, 123.5, 115.6, 106.4, 92.1, 91.7, 55.3, 53.8, 37.6, 31.9, 21.1, 12.8; Ion-trap-HRMS (ESI) calcd for $C_{29}H_{28}ClN_2O_3$ $[M+H]^+$ 487.1788, found 487.1999.

*4.2.17. 2-(2-Chlorobenzyl)-5-ethyl-7,9-dimethoxy-1-(phenylamino)-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11r**).* Yellow solid (70 mg, 48%), mp=162–164 °C; IR (KBr) 3450, 2923, 1642, 1519, 1268, 1039, 755 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39–7.28 (m, 4H), 7.15–7.07 (m, 5H), 6.56 (s, 1H), 6.55 (s, 1H), 6.08 (s, 1H), 4.43 (d, *J*=7.2 Hz, 2H), 3.86 (s, 3H), 3.81 (s, 2H), 2.93 (s, 3H), 1.39 (t, *J*=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.6, 159.6, 155.2, 142.8, 139.3, 137.7, 136.5, 134.7, 133.9, 130.9, 129.3, 128.6, 127.8, 126.9, 126.7, 126.5, 115.7, 106.4, 100.2, 92.2, 91.6, 55.4, 53.8, 37.6, 32.0, 12.8; Ion-trap-HRMS (ESI) calcd for $C_{28}H_{27}ClN_3O_3$ $[M+H]^+$ 488.1741, found 488.1756.

*4.2.18. 2-(2-Chlorobenzyl)-1-(3,5-dimethylphenyl)-5-ethyl-7,9-dimethoxy-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11s**).* Brown solid (93 mg, 62%), mp=167–168 °C; IR (KBr) 2924, 1647, 1457, 1286, 1080, 754 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.29–7.26 (m, 1H), 7.13–7.11 (m, 4H), 6.92 (s, 1H), 6.62 (s, 1H), 6.60 (s, 1H), 6.56 (s, 1H), 6.09 (s, 1H), 4.44 (d, *J*=7.2 Hz, 2H), 3.82 (s, 2H), 2.94 (s, 3H), 2.26 (s, 6H), 1.40 (t, *J*=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.6, 159.6, 155.3, 142.5, 139.3, 138.2, 137.7, 136.7, 134.6, 133.8, 130.8, 129.2, 128.4, 127.6, 126.6, 124.2, 115.5, 106.4, 100.4, 92.1, 91.7, 55.3, 53.7, 37.5, 31.9, 21.0, 12.8; Ion-trap-HRMS (ESI) calcd for $C_{30}H_{30}ClN_2O_3$ $[M+H]^+$ 501.1945, found 501.1962.

*4.2.19. 5-Ethyl-7,9-dimethoxy-2-(4-methylbenzyl)-1-(p-tolyl)-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11t**).* Brown syrup (116 mg, 83%);

IR (KBr) 2925, 1624, 1512, 1456, 1082, 754 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.15 (d, J=8.0 Hz, 2H), 7.02 (d, J=8.0 Hz, 2H), 6.93–6.89 (m, 4H), 6.64 (s, 1H), 6.55 (s, 1H), 6.07 (s, 1H), 4.43 (q, J=7.2 Hz, 2H), 3.86 (s, 3H), 3.67 (s, 2H), 2.94 (s, 3H), 2.39 (s, 3H), 2.29 (s, 3H), 1.39 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.7, 159.5, 155.2, 140.4, 139.7, 139.3, 136.5, 135.7, 135.6, 134.7, 128.9, 128.7, 128.6, 126.4, 115.5, 106.0, 100.4, 92.1, 91.6, 55.3, 53.8, 37.5, 33.9, 21.0, 21.0, 12.8; Ion-trap-HRMS (ESI) calcd for $C_{30}H_{31}N_2O_3$ $[M+H]^+$ 467.2335, found 467.2351.

*4.2.20. 5-Ethyl-7,9-dimethoxy-2-(4-nitrobenzyl)-1-(p-tolyl)-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11u**).* Brown syrup (111 mg, 78%); IR (KBr) 2922, 1640, 1531, 1435, 1268, 755 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 8.01 (d, J=8.0 Hz, 2H), 7.12–7.08 (m, 4H), 6.82 (d, J=8.0 Hz, 2H), 6.78 (s, 1H), 6.56 (s, 1H), 6.07 (s, 1H), 4.44 (q, J=7.2 Hz, 2H), 3.88 (s, 3H), 3.86 (s, 2H), 2.93 (s, 3H), 2.38 (s, 3H), 1.40 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.8, 159.6, 155.3, 146.6, 146.5, 140.1, 139.5, 137.1, 136.9, 135.1, 129.4, 129.0, 126.4, 123.3, 115.4, 106.8, 100.1, 92.2, 91.7, 55.3, 53.8, 37.6, 34.2, 21.0, 12.8; Ion-trap-HRMS (ESI) calcd for $C_{29}H_{28}N_3O_5$ $[M+H]^+$ 498.2029, found 498.2047.

*4.2.21. 5-Ethyl-7,9-dimethoxy-2-(4-nitrobenzyl)-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11v**).* Brown syrup (89 mg, 73%); IR (KBr) 2940, 1642, 1556, 1437, 1245, 1012, 754 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.32–7.30 (m, 1H), δ 9.34 (s, 1H), 8.15 (d, J=8.4 Hz, 2H), 7.38 (d, J=8.4 Hz, 2H), 6.62 (s, 1H), 6.57 (s, 1H), 6.38 (s, 1H), 4.41 (q, J=7.2 Hz, 2H), 4.21 (s, 2H), 3.99 (s, 3H), 3.91 (s, 3H), 1.36 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.8, 159.6, 156.3, 146.3, 138.7, 133.5, 131.2, 129.3, 123.8, 113.0, 104.7, 98.9, 92.5, 92.1, 56.0, 55.5, 37.3, 34.1, 12.9; Ion-trap-HRMS (ESI) calcd for $C_{22}H_{22}N_3O_5$ $[M+H]^+$ 408.1559, found 408.1577.

*4.2.22. 2-(2,6-Dimethylbenzyl)-5-ethyl-7,8-dimethoxy-1-(p-tolyl)-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11w**).* Yellow solid (79 mg, 55%), mp=119–121 °C; IR (KBr) 2923, 1642, 1519, 1452, 1208, 755 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.48 (d, J=8.0 Hz, 2H), 7.42 (d, J=8.0 Hz, 2H), 7.09–7.01 (m, 3H), 6.87 (s, 1H), 6.33 (s, 1H), 6.15 (s, 1H), 4.42 (q, J=7.2 Hz, 2H), 3.93 (s, 3H), 3.64 (s, 2H), 3.33 (s, 3H), 2.51 (s, 3H), 2.21 (s, 6H), 1.35 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.1, 148.5, 143.7, 139.7, 137.1, 136.7, 136.4, 134.6, 131.6, 130.7, 128.9, 128.1, 126.6, 114.4, 107.8, 103.9, 103.4, 98.9, 56.0, 54.9, 37.0, 27.6, 21.2, 19.7, 13.0; Ion-trap-HRMS (ESI) calcd for $C_{31}H_{33}N_2O_3$ $[M+H]^+$ 481.2491, found 481.2479.

*4.2.23. 2-(2-Chlorobenzyl)-5-ethyl-7,8-dimethoxy-1-(p-tolyl)-1H-pyrrolo[3,2-c]quinolin-4(5H)-one (**11x**).* Brown solid (109 mg, 75%), mp=184–186 °C; IR (KBr) 2925, 1641, 1577, 1465, 1268, 1039, 755 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.34 (d, J=8.0 Hz, 2H), 7.29–7.28 (m, 1H), 7.22 (d, J=8.0 Hz, 2H), 7.16–7.14 (m, 3H), 6.87 (s, 1H), 6.59 (s, 1H), 6.27 (s, 1H), 4.45 (q, J=7.2 Hz, 2H), 3.93 (s, 3H), 3.89 (s, 2H), 3.29 (s, 3H), 2.45 (s, 3H), 1.38 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.1, 148.6, 143.7, 139.6, 136.7, 136.2, 135.9, 134.0, 134.0, 131.7, 130.8, 130.4, 129.3, 129.0, 127.9, 126.7, 114.4, 107.8, 105.5, 103.4, 98.9, 56.0, 54.8, 37.1, 30.7, 21.2, 13.0; Ion-trap-HRMS (ESI) calcd for $C_{29}H_{28}ClN_2O_3$ $[M+H]^+$ 487.1788, found 487.1799.

4.3. General procedure for the synthesis of 19 from 11 via direct arylation

K_2CO_3 (0.2 mmol), $Pd(OAc)_2$ (10 mol %), and PPh_3 (20 mol %) were subsequently added to the stirred solution of **11** (0.1 mmol) in dry toluene (2 mL) in a Schlenk flask under nitrogen atmosphere. The reaction mixture was heated at 120 °C until the disappearance of the starting material (approximately 16 h) according to TLC. H_2O (5 mL) was then added to the reaction mixture. The resulting mixture was extracted with AcOEt (3×5 mL). The combined organic extracts were washed with brine, dried over Na_2SO_4, filtered, and concentrated. The residue was purified by flash column chromatography (using petroleum ether/ethyl acetate (3:1) as the eluent) to give **19**.

*4.3.1. 5-Ethyl-2,3,4-trimethoxy-12-phenyl-11,12-dihydro-5H-5,12-diaza-benzo[5,6]pentaleno[2,1-b]naphthalen-6-one (**19g**).* Brown solid (33 mg, 64%), mp=192–193 °C; IR (KBr) 2928, 1646, 1552, 1458, 1223, 1049, 745 cm^{-1}; IR (KBr) 2928, 1646, 1552, 1458, 1223, 1049, 745 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 8.39 (d, J=7.6 Hz, 1H), 7.44 (t, J=8.0 Hz, 2H), 7.38–7.33 (m, 4H), 7.30–7.27 (m, 2H), 7.12 (t, J=8.4 Hz, 1H), 6.74 (s, 1H), 4.52 (q, J=8.0 Hz, 2H), 3.98 (s, 3H), 3.70 (s, 3H), 3.57 (s, 2H), 3.26 (s, 3H), 1.49 (t, J=7.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.6, 153.1, 148.1, 147.8, 143.1, 142.8, 138.6, 137.2, 136.0, 134.4, 129.1, 127.3, 126.9, 126.8, 124.3, 123.6, 122.3, 112.1, 104.2, 94.2, 61.2, 60.0, 56.2, 37.6, 32.3, 13.0; Ion-trap-HRMS (ESI) calcd for $C_{29}H_{27}N_2O_4$ $[M+H]^+$ 467.1971, found 467.1982.

*4.3.2. 5-Ethyl-2,3,4-trimethoxy-12-p-tolyl-11,12-dihydro-5H-5,12-diaza-benzo[5,6]pentaleno[2,1-b]naphthalen-6-one (**19h**).* Brown solid (44 mg, 85%), mp=195–196 °C; IR (KBr) 2919, 1642, 1559, 1460, 1265, 1040, 749 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 8.39 (d, J=7.6 Hz, 1H), 7.37–7.34 (m, 2H), 7.22 (d, J=8.0 Hz, 2H), 7.17–7.10 (m, 3H), 6.73 (s, 1H), 4.51 (q, J=7.2 Hz, 2H), 3.98 (s, 3H), 3.72 (s, 3H), 3.53 (s, 2H), 3.27 (s, 3H), 2.42 (s, 3H), 1.49 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.6, 153.1, 148.2, 147.9, 142.8, 140.6, 138.7, 137.3, 136.5, 136.0, 134.4, 129.6, 127.2, 126.6, 124.3, 123.7, 123.4, 122.3, 111.9, 104.4, 94.2, 61.3, 60.1, 56.2, 37.6, 32.3, 21.1, 13.0; Ion-trap-HRMS (ESI) calcd for $C_{30}H_{29}N_2O_4$ $[M+H]^+$ 481.2127, found 481.2135.

*4.3.3. 5-Ethyl-2,3,4-trimethoxy-12-(3-methoxy-phenyl)-11,12-dihydro-5H-5,12-diaza-benzo[5,6]pentaleno[2,1-b]naphthalen-6-one (**19i**).* Brown solid (48 mg, 60%), mp=201–203 °C; IR (KBr) 2936, 1626, 1545, 1438, 1271, 1046, 735 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 8.39 (d, J=7.6 Hz, 1H), 7.38–7.31 (m, 3H), 7.12 (t, J=7.6 Hz, 1H), 6.90–6.88 (m, 2H), 6.81 (s, 1H), 6.73 (s, 1H), 4.51 (q, J=6.8 Hz, 2H), 3.98 (s, 3H), 3.79 (s, 3H), 3.72 (s, 3H), 3.59 (s, 2H), 3.32 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 160.3, 159.6, 153.3, 148.4, 147.7, 144.3, 142.9, 138.8, 137.4, 136.0, 134.6, 129.8, 127.4, 126.7, 124.3, 123.8, 122.3, 116.1, 112.3, 112.1, 111.3, 104.2, 100.0, 94.2, 61.3, 60.4, 56.3, 55.6, 37.7, 32.5, 13.1; Ion-trap-HRMS (ESI) calcd for $C_{30}H_{29}N_2O_5$ $[M+H]^+$ 497.2076, found 497.2058.

*4.3.4. 5-Ethyl-2,3,4-trimethoxy-12-(4-nitro-phenyl)-11,12-dihydro-5H-5,12-diaza-benzo[5,6]pentaleno[2,1-b]naphthalen-6-one (**19k**).* Brown syrup (48 mg, 60%), mp=243–245 °C; IR (KBr) 2935, 1625, 1553, 1427, 1252, 1022, 748 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 8.40 (d, J=8.0 Hz, 1H), 8.32 (d, J=9.2 Hz, 2H), 7.44 (d, J=9.2 Hz, 2H), 7.16 (t, J=6.4 Hz, 1H), 6.77 (s, 1H), 4.52 (q, J=7.2 Hz, 2H), 4.00 (s, 3H), 3.73 (s, 3H), 3.61 (s, 2H), 3.34 (s, 3H), 1.50 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.4, 153.7, 148.5, 147.6, 146.6, 146.0, 142.3, 137.9, 137.7, 136.1, 134.7, 128.2, 127.5, 124.8, 124.4, 122.9, 122.6, 113.0, 103.7, 94.8, 61.5, 60.3, 56.2, 37.7, 32.4, 13.0; Ion-trap-HRMS (ESI) calcd for $C_{29}H_{26}N_3O_6$ $[M+H]^+$ 512.1822, found 512.1810.

4.4. General procedure for the synthesis of 19 from 11 via a dehydrogenative coupling

$Pd(OAc)_2$ (11.2 mg, 0.05 mmol, 5.0 mol %), $Cu(OAc)_2$·(182 mg, 1.0 mmol), PivOH (250 mg, 2.5 mmol), and **11** (0.5 mmol) in dry toluene(3 mL) were stirred in a sealed tube at 140 °C for 20 h. H_2O (50 mL) was added at ambient temperature, and the resulting mixture was extracted with EtOAc(3×50 mL). The combined organic layers were washed with satd aq NH_4Cl (50 mL), H_2O (50 mL), and brine (50 mL), dried over Na_2SO_4, filtered, and concentrated in

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vacuo. The residue was purified by flash column chromatography (using petroleum ether/ethyl acetate=10:1 as the eluent) to give **19**.

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Supplementary data

Details on CIF information of **11n**, scanned photocopies of ^{1}H and ^{13}C NMR spectral data were supported. Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.tet.2014.05.084.

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16. Crystallographic data for the structures of **11n** has been deposited with the Cambridge Crystallographic Data Center as supplementary publications number (CCDC 822029).