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Tetrahedron
Tetrahedron 63 (2007) 2024–2033

Synthesis of polycyclic indolizine derivatives via one-pot tandem reactions of *N*-ylides with dichloro substituted α,β-unsaturated carbonyl compounds

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Received 3 August 2006; revised 14 December 2006; accepted 18 December 2006
Available online 20 December 2006

Abstract—Convenient and regioselective syntheses of 1,2-annulated, and 1,2-, 5,6- and 1,2-, 7,8-bisannulated polycyclic indolizine derivatives have been achieved by one-pot tandem reactions of cyclic *N*-ylides derived from the corresponding *N*-substituted pyridinium, quinolinium, and isoquinolinium salts **1**–**3** with dichloro substituted α,β-unsaturated carbonyl compounds **4**–**7**. The reactions of the *N*-ylides with 2,3-dichloroindenone **4**, 3,4-dichlorocoumarin **5**, and 4a,6,7,8a-tetrachloro-1,4-methanonaphthalene-5,8-dione **6** proceed by sequential [3+2] cycloaddition and elimination of hydrogen chlorides from the cycloadducts. On the other hand, reactions of the *N*-ylides with 2,3-dichloro-1,4-naphthoquinone **7** take place via a novel reaction sequence to give the products **15**–**17**.

1. Introduction

As a non-alternative heteroaromatic system, indolizine has a special electronic structure, which has long drawn much theoretical interest.[1,2] Besides, indolizine derivatives have been found to possess a variety of biological activities such as anti-inflammatory,[3] antiviral,[4] aromatase inhibitory,[5] analgestic,[6] and antitumor[7] activities. They have also shown to be calcium entry blockers[8] and potent antioxidants inhibiting lipid peroxidation in vitro.[9] As such, indolizines are important synthetic targets in view of developing new pharmaceuticals for the treatment of cancer,[7] cardiovascular diseases,[3b,10] and HIV infections.[11] In particular, indolizines annulated at the 1,2-positions are found in several naturally occurring alkaloids with important biological activity, such as in camptothecin[12] and nuevamine.[13] A few synthetic 1,2-annulated indolizines have also displayed interesting biological activity to serve as brain protecting and anticancer agents.[14] In addition, polycyclic indolizine derivatives have been found to have long wavelength absorption and fluorescence in the visible region. The synthesis of these types of compounds has drawn the great interest of chemists to develop, for example, novel classes of dyes and biological markers.[15]

However, investigation of the biological activities and optoelectric properties of these annulated polycyclic indolizines is still largely impeded by the lack of efficient and general synthetic methods. A few highly specific synthetic methods have been reported, but are rather lengthy and give low overall yields.[16]

Recently, isoindolo[2,1-*a*]quinolin-11-ones have been synthesized by [4+2] cycloadditions of acyliminium cation with alkenes.[17] Although [3+2] cycloaddition of pyridinium and quinolinium ylides has been applied for the synthesis of indolizines, these reactions were mainly limited to the use of electron deficient alkynes as dipolarophile.[18] In the case of alkenes, unstable tetrahydroindolizines are formed, which reversibly transform into a betaine intermediate followed by decomposition.[19] However, two recent approaches have succeeded in extending the [3+2] reaction to the application of alkenes as dipolarophiles. By using fluoroalkenes, fluoroiodoalkenes, and fluorinated vinyl tosylates[20–22] in the cycloadditions with the pyridinium and quinolinium ylides followed by elimination of hydrogen fluoride and toluenesulfonic acid, fluorinated and unfluorinated indolizines can be prepared. Meanwhile, Hu and co-workers reported that by using a mild dehydrogenative oxidant tetrakispyridinecobalt(II) dichromate [$Py_4Co(HCrO_4)_2$] (TPCD), the tetrahydroindolizines can be in situ dehydrogenated to indolizines.[23] In this way, several 1,2-annulated indolizines were prepared by cycloadditions of pyridinium and quinolinium ylides with naphthoquinones, etc.[24] We report here a general and versatile synthesis of 1,2-annulated indolizines by one-pot tandem reactions of pyridinium, quinolinium, and isoquinolinium ylides with cyclic 1,2-dichloroalkenes **4**–**7**. We have also shown that the reactions of the *N*-ylides

Keywords: Annulated indolizines; Pyridinium ylides; Quinolinium ylides; Isoquinolinium ylides; [3+2] Cycloadditions.
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0040–4020/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tet.2006.12.050

with 2,3-dichloroindenone **4**, 3,4-dichlorocoumarin **5**, and 4a,6,7,8a-tetrachloro-1,4-methanonaphthalene-5,8-dione **6** proceed via [3+2] cycloaddition and elimination of two hydrogen chloride molecules, while the reactions of the *N*-ylides with 2,3-dichloro-1,4-naphthoquinone **7** take place by a novel mechanism involving sequential nucleophilic substitutions and a formal retro-Menschutkin reaction. By these one-pot tandem reactions of the *N*-ylides with **4**–**7**, 1,2-annulated, and 1,2-, 5,6-, and 1,2-, 7,8- bisannulated polycyclic indolizine derivatives can be conveniently and regioselectively prepared from easily accessible starting materials.

2. Results and discussion

Reactions of the *N*-ylides derived from the pyridinium salts **1**, isoquinolinium salts **2**, and quinolinium salts **3** with the dichloro substituted α,β-unsaturated carbonyl compounds **4**–**7** have been investigated (Fig. 1). Pyridinium phenacylide generated in situ by the deprotonation of phenacyl pyridinium fluoroborate **1a** (1.1 mmol) with sodium carbonate (3.5 mmol) as a base was allowed to react with 2,3-dichloroindenone **4** (1.0 mmol) at 50 °C for 24 h to lead to complete conversion of **4**. Chromatographic separation of the reaction mixture gave the indeno[2,1-*a*]indolizin-11-one **8** directly in 42% yield. Reactions of the same ylide from **1a** with 3,4-dichlorocoumarin **5** similarly afforded the corresponding 1,2-annulated indolizine **9** in 38% yield (Table 1). At the same time, reaction of pyridinium ethoxycarbonylmethylide (from **1b**) with 4a,6,7,8a-tetrachloro-1,4-methanonaphthalene-5,8-dione **6** under similar conditions afforded the indolizine **10** (63%). These products are fully characterized by spectral (IR, ^{1}H NMR, and MS) and analytical data. Notably, the ^{1}H NMR spectra of **10** are characterized by an unusually low field absorption (δ 9.8–9.9 ppm) of the proton at C1 (see compound **10** in Fig. 1) caused by the strong anisotropic deshielding effect of the nearby carbonyl group.

We have further investigated the reactions of the isoquinolinium ylides derived from **2a**–**2d** and quinolinium ylides from **3a**–**3c** with dichloroalkenes **4** and **6**. These reactions also led to the one-pot synthesis of the corresponding 1,2-annulated indolizines **11**–**14** as pentacyclic compounds in moderate to high yields (Table 1). The structures of these products are further supported by an X-ray crystallographic analysis of **12a** (Fig. 2).

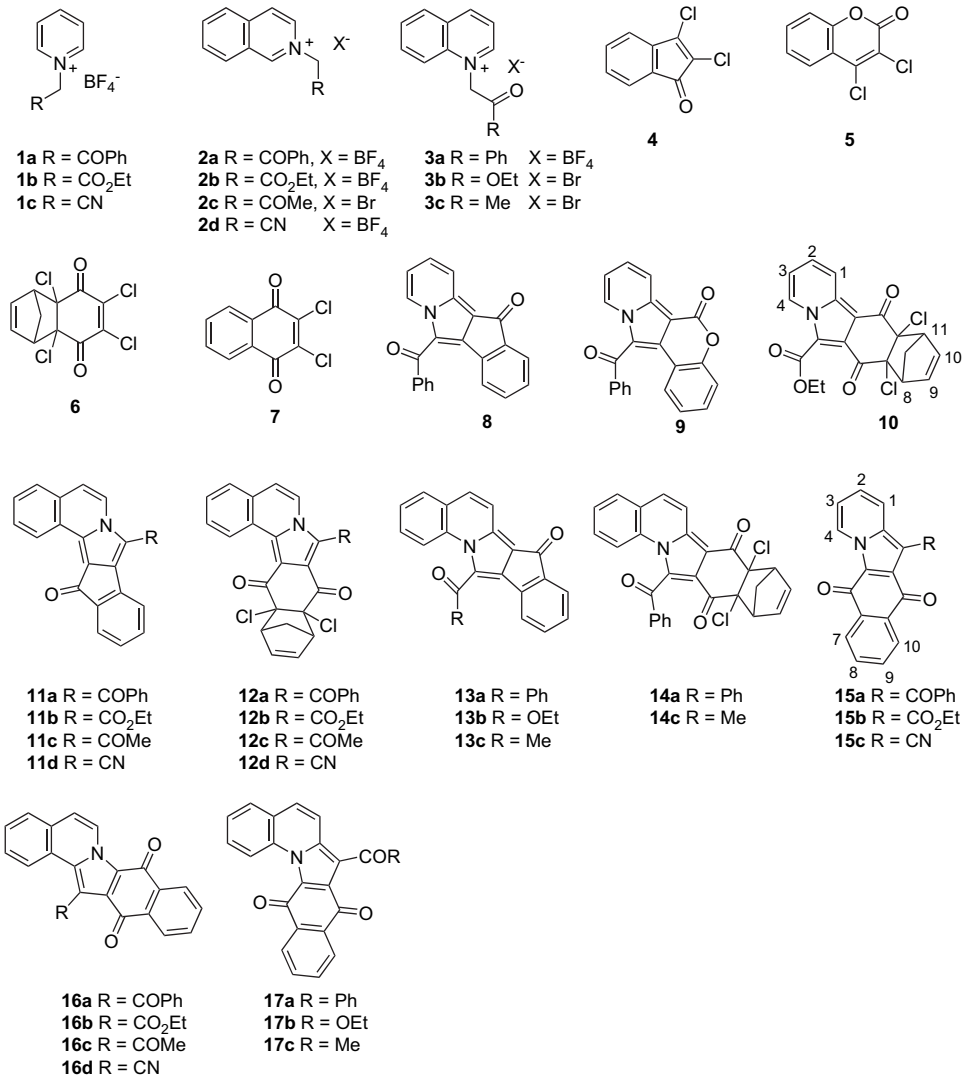


Figure 1.

Table 1. Reactions of *N*-ylides (**1–3**) with dichloroalkenes (**4–7**)[a]

Ylide precursor	Alkene	Product and yield[b] (%)	Ylide precursor	Alkene	Product and yield[b] (%)
1a	**4**	**8** (42)	**3b**	**4**	**13b** (28)
1a	**5**	**9** (38)	**3c**	**4**	**13c** (30)
1b	**6**	**10** (83)	**3c**	**6**	**14c** (60)
2a	**4**	**11a** (50)	**1a**	**7**	**15a** (56)
2a	**6**	**12a** (82)	**1b**	**7**	**15b** (58)
2b	**4**	**11b** (45)	**1c**	**7**	**15c** (58)
2b	**6**	**12b** (83)	**2a**	**7**	**16a** (76)
2c	**4**	**11c** (46)	**2b**	**7**	**16b** (78)
2c	**6**	**12c** (90)	**2c**	**7**	**16c** (85)
2d	**4**	**11d** (46)	**2d**	**7**	**16d** (70)
2d	**6**	**12d** (85)	**3a**	**7**	**17a** (60)
3a	**4**	**13a** (40)	**3b**	**7**	**17b** (42)
3a	**6**	**14a** (65)	**3c**	**7**	**17c** (45)

[a] All the reactions were carried out in MeCN solution with K_2CO_3 (3.5 equiv) as base at 50 °C for 24 h.
[b] Yield of isolated products.

It is noteworthy that the reactions of the ylide from **1a** with alkenes **4** and **5**, and the reaction of the ylides from **2** and **3** with alkene **4** are highly regioselective to give only a single product (**8**, **9**, **11**, and **13**) without their regioisomers. The regiochemistry in **13a** is unambiguously established by an X-ray crystallographic analysis (Fig. 3).

These reactions are assumed to proceed via a reaction sequence of [3+2] cycloaddition of the *N*-ylide with the dichloroalkene and subsequent elimination of two molecules of hydrogen chloride under the reaction conditions (Scheme 1). The [3+2] cycloadditions may take place either by direct concerted 1,3-dipolar cycloaddition between the *N*-ylide and the alkene[25] or by a primary Michael addition of the ylide to the alkene[26] followed by cyclization of the zwitterion

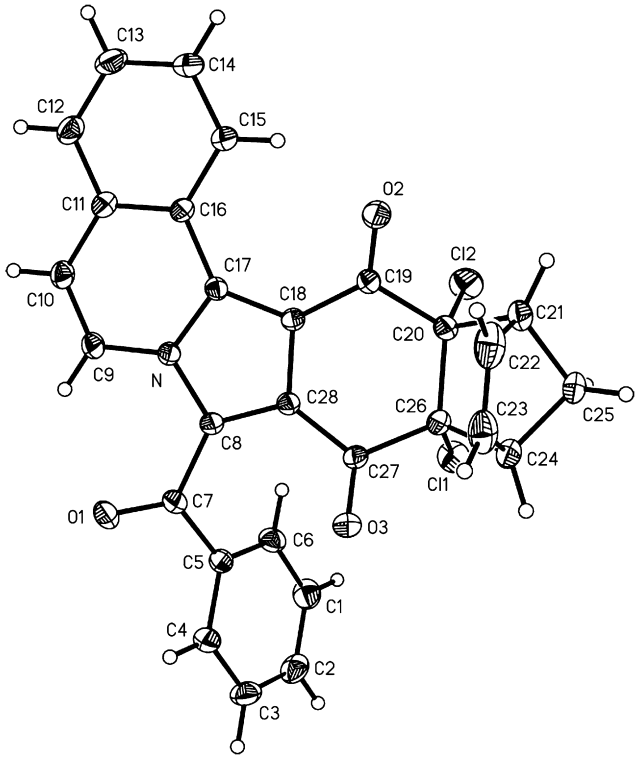


Figure 2. ORTEP drawing of **12a**.

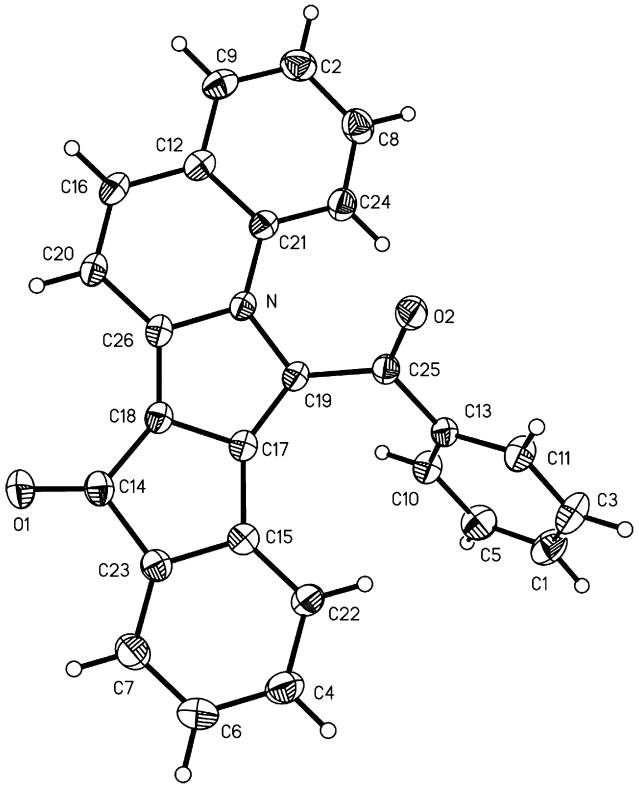
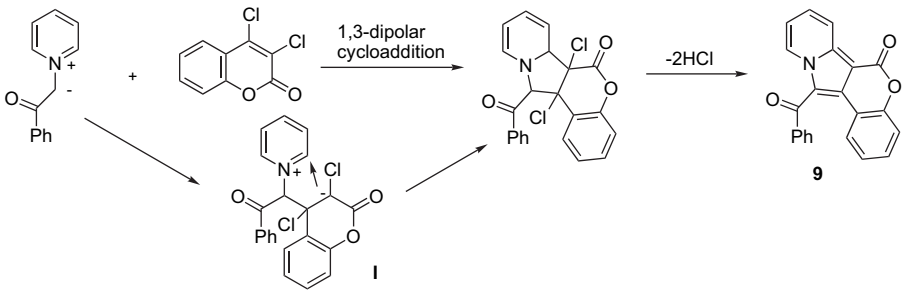


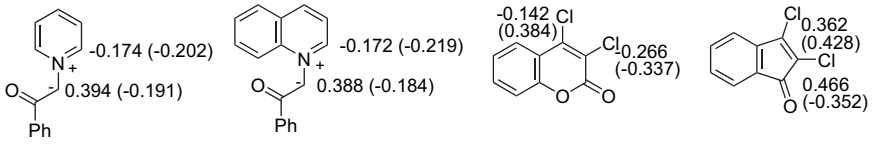
Figure 3. ORTEP drawing of **13a**.

intermediate (Scheme 1). The regioselectivity in the formation of **8**, **9**, **11**, and **13** can also be rationalized within the frames of the two mechanisms. Therefore, the frontier molecular orbitals of the ylides derived from **1a** and **3a**, and of the dichloroalkenes **4** and **5** were calculated by DFT method at the B3LYP 6-31G level[27] as shown in Figure 4. It is seen that while HOMO(**5**)–LUMO(pyridinium ylide) interaction is not highly discriminative in differentiating the two possible regioselectivity because of the similar magnitudes of the atomic coefficients at the 1,3-dipolar reacting centers in the ylide, maximum positive orbital overlap in the dominating LUMO(**5**)–HOMO(pyridinium ylide) interaction with a smaller energy gap leads to a definite regioselectivity as actually seen in **9**. Regioselectivity in product **13a** is also in agreement with the FMO interaction consideration, here again the LUMO(**4**)–HOMO(quinolinium ylide) interaction plays a dominant role in determining the regioselectivity although it has a slightly larger energy gap than in the HOMO(**4**)–LUMO(quinolinium ylide) interaction, which is not highly discriminative in determining regioselectivity because of the similar atomic coefficient magnitudes at the 1,3-dipolar reacting centers in the ylide. In route 2, as is usually the case in Michael addition to an α,β-unsaturated carbonyl compound, the carbanionic carbon atom in the ylide takes part in an 1,4-addition to the α,β-unsaturated alkene **5** to give the zwitterion(**I**) regioselectively, which furnished **9** by cyclization and elimination of two hydrogen chloride molecules.

We have further investigated the reactions of 2,3-dichloro-1,4-naphthoquinone **7** with the *N*-ylides derived from **1–3**. However, we found that these reactions did not follow the normal [3+2] cycloaddition pathway but took place by an



Scheme 1.



	ylide from **1a**	ylide from **3a**	**5**	**4**
E_{HOMO}(a.u.)	-0.18025	-0.17726	-0.25929	-0.18673
E_{LUMO}(a.u.)	-0.06881	-0.08550	-0.09687	-0.03176

Figure 4. FMO energies and atomic coefficients of pyridinium and quinolinium ylides and compounds **4** and **5**. LUMO coefficients in parenthesis.

entirely different pathway. Therefore, reaction of the ylide from **1a** with **7** in MeCN under same conditions as mentioned above afforded the product benzo[*f*]pyrido[1,2-*a*]-indole-6,11-dione **15a** in 56% yield instead of the expected benzo[*f*]pyrido[2,1-*a*]isoindole-7,12-dione. Similar reaction of **7** with the ylides derived from **1b** and **1c** furnished products **15b** (58%) and **15c** (58%), respectively. The structure of **15b** is unambiguously established by an X-ray crystallographic analysis (Fig. 5). Similar to compound **10**, in the ^{1}H NMR spectra of **15a**–**15c**, the protons at C4 (see formula **15a**–**15c** in Fig. 1) absorb at a remarkably low field with δ values in the region 9.75–9.9 ppm due to the deshielding effect of the nearby carbonyl group. Reaction of **7** with the *N*-ylides generated from **2** and **3** gave products **16** and **17** in moderate to high yields, respectively (Table 1). Their structures are further confirmed by an X-ray crystallographic analysis of product **16c** (Fig. 6).

Since the substituent at the nitrogen atom in the *N*-ylides derived from **1**–**3** has disconnected with the *N* atom in the products **15**, **16**, and **17**, they were obviously not formed via mechanisms shown in Scheme 1. Taking into account of the fact that **7** is a highly activated halide in which the Cl atoms are prone to be substituted (as in an acyl halide) by nucleophiles, we propose that these reactions proceed by a mechanism shown in Scheme 2 with the reaction of **7** with **1a** as an example.

Nucleophilic attack of the anionic center in the ylide at the =C–Cl functionality in **7** could result in release of the chloride anion, which could attack the α-carbon atom in the phenancyl group in the intermediate **II** in a S_N2 fashion with pyridine as a leaving group, leading to a formal retro-Menschutkin reaction of the *N*-phenancyl pyridinium salt to give **III**.[28] Nucleophilic attack of pyridine at the =C–Cl

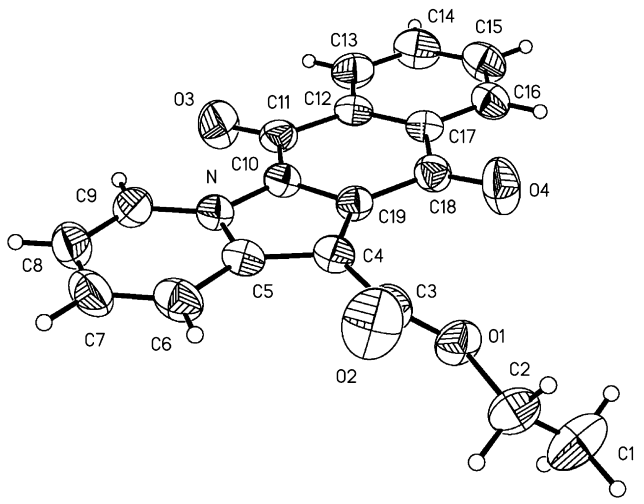


Figure 5. ORTEP drawing of **15b**.

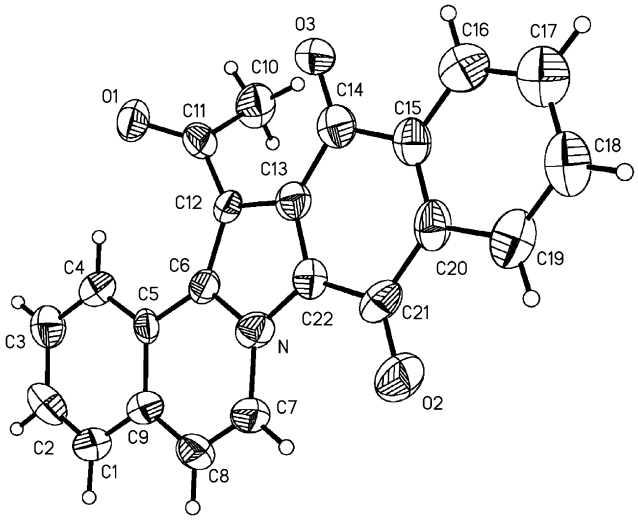
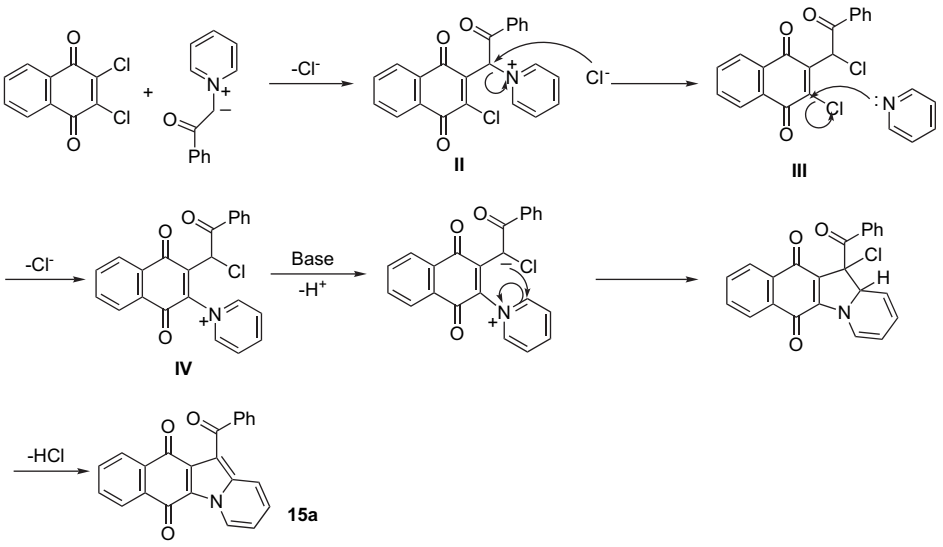


Figure 6. ORTEP drawing of **16c**.



Scheme 2.

bond in **III** could give the pyridinium salt **IV**.[29] Deprotonation in **IV** followed by cyclization and elimination of a hydrogen chloride molecule affords product **15a**.

3. Conclusion

In summary, general and straightforward synthesis of 1,2-annulated polycyclic indolizines can be achieved by one-pot tandem reactions of the pyridinium, quinolinium, and isoquinolinium ylides derived from **1**–**3** with cyclic dichloroalkenes **4**, **5**, **6**, and **7**. The reactions of the *N*-ylides with **4**–**6** proceed via sequential [3+2] cycloaddition and spontaneous elimination of two hydrogen chloride molecules from the cycloadducts under the reaction conditions. In contrast, reactions of the *N*-ylides with 2,3-dichloro-1,4-naphthoquinone **7** are proposed to take place via a novel mechanism involving sequential reactions as shown in Scheme 2. In these reactions, a series of novel polycyclic indolizine derivatives annulated at 1,2-positions and bisannulated at 1,2-, 5,6- and 1,2-, 7,8-positions by carbo- or heterocycles have been conveniently prepared in moderate to high yields from easily accessible starting materials. For the unsymmetrical alkenes **4** and **5**, the reactions take place regioselectively to give one regioisomer exclusively. This array of polycyclic indolizine derivatives is interesting target compounds for screening biological activity. Also, because of their strong absorption and fluorescence in the visible region, they should be of interest for the investigation of opto-electric materials.

4. Experimental

4.1. General

Melting points are uncorrected. ^{1}H NMR spectra were measured on a Bruker DPX 300 spectrometer at 300 MHz with $CDCl_3$ as solvent unless otherwise stated. The chemical shifts (δ) are reported in parts per million relative to the residual deuterated solvent signal, and coupling constants (J) are given in Hertz. ^{13}C NMR spectra were measured on a Bruker Avance 300 spectrometer at 75 MHz with $CDCl_3$ as solvent. IR spectra were recorded with a Shimadzu IR 440 spectrometer as KBr pellets. Mass spectra were taken on a VG ZAB-HS spectrometer in the electron impact ionization mode. Elemental analyses were performed with a Perkin–Elmer 240C analyzer. For X-ray Crystallographic analysis, the X-ray diffraction intensities and the unit cell parameters were determined on a Siemens P4 diffractometer employing graphite-monochromated (Mo Kα) radiation (λ=0.71073 Å) and operating in the $\omega-2\theta$ scan mode. Data collection and cell refinement were performed with XSCANS. Structures were solved by direct methods and refined by full-matrix least-squares on F^2 with SHELXTL. Non-hydrogen atoms were refined by anisotropic displacement parameters, and the positions of all H-atoms were fixed geometrically and included in estimated positions using a riding model.

Crystallographic data (excluding structure factors) for the structures in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication numbers CCDC 602715, CCDC 602716, CCDC 616322, and CCDC 616323. Copies of the data can be obtained, free of charge, on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK [fax: +44(0) 1223 336033 or e-mail: deposit@ccdc.cam.ac.uk].

4.2. Syntheses of 8, 9, 10, and 15; general procedure

A mixture of a pyridinium salt (**1a**–**1c**, 1.1 mmol), a dichloro substituted α,β-unsaturated carbonyl compounds (**4**–**7**, 1 mmol), and potassium carbonate (0.48 g, 3.5 mmol) in MeCN (15 ml) was heated at 50 °C for 24 h with magnetic stirring. The reaction was monitored by TLC. The solvent was removed under reduced pressure, and the residue was separated by flash chromatography on a silica gel column with petroleum ether (bp 60–90 °C)/ethyl acetate as an eluent to give the products **8**–**10** and **15**.

4.2.1. 6-Benzoyl-11*H*-indeno[2,1-*a*]indolizin-11-one (8). Yield: 42%; yellow solid from petroleum ether (bp

60–90 °C)/chloroform; mp 92–93 °C. IR (KBr) ν 3069, 1648, 1623, 1598, 1556, 1501, 1447, 1284, 1231, 1170, 1141, 719 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 6.31 (d, 1H, J=7.5 Hz), 6.84 (td, 1H, J=7.6 Hz, 1.2 Hz), 7.04 (td, 1H, J=7.7 Hz, 0.8 Hz), 7.24–7.39 (m, 3H), 7.72 (td, 2H, J=8.1 Hz, 1.4 Hz), 7.81 (t, 2H, J=7.3 Hz), 8.15 (t, 1H, J=7.7 Hz), 8.66 (d, 2H, J=5.6 Hz). MS m/z (%) 323 (M^+, 50), 294 (18), 246 (15), 190 (14), 105 (100), 77 (45). Anal. Calcd for $C_{22}H_{13}NO_2$: C, 81.73; H, 4.02; N, 4.33. Found: C, 81.65; H, 3.89; N, 4.40.

4.2.2. 12-Benzoyl-6*H*-[1]benzopyrano[3,4-*a*]indolizin-6-one (9). Yield: 38%; red solid from petroleum ether (bp 60–90 °C)/chloroform; mp 249–250 °C. IR (KBr) ν 3112, 1711, 1604, 1500, 1462, 1437, 1377, 1341, 1250, 1013, 765, 720 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 6.97 (t, 1H, J=7.6 Hz), 7.09–7.15 (m, 3H), 7.21 (d, 1H, J=8.2 Hz), 7.33 (td, 1H, J=8.2 Hz, 1.3 Hz), 7.43–7.47 (m, 2H), 7.54 (d, 1H, J=8.0 Hz), 7.68 (t, 2H, J=7.0 Hz), 7.91 (t, 1H, J=7.7 Hz), 8.78 (d, 2H, J=5.9 Hz). MS m/z (%) 339 (M^+, 48), 267 (15), 262 (22), 228 (12), 206 (13), 165 (17), 105 (100), 77 (69). Anal. Calcd for $C_{22}H_{13}NO_3$: C, 77.88; H, 3.83; N, 4.13. Found: C, 77.96; H, 3.81; N, 4.10.

4.2.3. 6-Ethoxycarbonyl-7a,11a-dichloro-7a,8,11,11a-tetrahydro-8,11-methanobenzo[*f*]pyrido[2,1-*a*]isoindole-7,12-dione (10). Yield: 63%; red solid from petroleum ether (bp 60–90 °C)/chloroform; mp 156–158 °C. IR (KBr) ν 3120, 2982, 2954, 1702, 1661, 1632, 1535, 1518, 1503, 1455, 1389, 1339, 1248, 1217, 1169, 1097, 1030, 919, 760, 710 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 1.42 (t, 3H, J=7.1 Hz), 2.06 (d, 1H, J=9.2 Hz), 2.58 (d, 1H, J=9.6 Hz), 3.71 (d, 2H, J=7.6 Hz), 4.41–4.54 (m, 2H), 6.16–6.21 (m, 2H), 7.23 (td, 1H, J=7.0 Hz, 1.3 Hz), 7.54 (td, 1H, J=7.0 Hz, 1.1 Hz), 8.45 (dd, 2H, J=9.0 Hz, 1.1 Hz), 9.56 (dd, 1H, J=7.2 Hz, 1.0 Hz). MS m/z (%) 403 (M^+, 22), 368 (23), 337 (100), 265 (95), 202 (62), 174 (47), 138 (57), 66 (48). Anal. Calcd for $C_{20}H_{15}NO_4Cl_2$: C, 59.55; H, 3.72; N, 3.47. Found: C, 59.63; H, 3.78; N, 3.52.

4.2.4. 12-Benzoylbenzo[*f*]pyrido[1,2-*a*]indole-6,11-dione (15a). Yield: 56%; yellow solid from petroleum ether (bp 60–90 °C)/chloroform; mp 255–256 °C (lit.[29a] 256–257.5 °C). IR (KBr) ν 3112, 1671, 1627, 1591, 1497, 1450, 1398, 1368, 1314, 1278, 1231, 1163, 907, 812, 760 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 7.21 (dd, 1H, J=7.1 Hz, 1.2 Hz), 7.41–7.50 (m, 3H), 7.58–7.68 (m, 2H), 7.75 (td, 1H, J=7.3 Hz, 1.4 Hz), 7.90–7.99 (m, 3H), 8.04 (dd, 1H, J=7.7 Hz, 1.1 Hz), 8.27 (dd, 1H, J=7.7 Hz, 1.1 Hz), 9.83 (dt, 1H, J=7.1 Hz, 1.1 Hz). MS m/z (%) 351 (M^+, 62), 274 (100), 255 (12), 227 (20), 190 (34), 185 (29), 170 (14), 77 (20). Anal. Calcd for $C_{23}H_{13}NO_3$: C, 78.63; H, 3.70; N, 3.99. Found: C, 78.80; H, 3.61; N, 4.06.

4.2.5. 12-Ethoxycarbonylbenzo[*f*]pyrido[1,2-*a*]indole-6,11-dione (15b). CCDC No. 616323. Yield: 58%; red solid from petroleum ether (bp 60–90 °C)/chloroform; mp 154–155 °C (lit.[29e] 157–158 °C). IR (KBr) ν 3120, 2976, 2929,1695, 1673, 1638, 1626, 1590, 1510, 1485, 1474, 1229, 1208, 746, 713 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 1.52 (t, 3H, J=7.1 Hz), 4.54 (q, 2H, J=7.1 Hz), 7.19 (t, 1H, J=6.9 Hz), 7.45 (td, 1H, J=8.0 Hz, 1.0 Hz), 7.72–7.76 (m, 2H), 8.23–8.25 (m, 2H), 8.33 (dd, 1H, J=9.1 Hz, 1.0 Hz), 9.87 (dd, 1H, J=7.0 Hz, 1.0 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 14.7, 30.1, 106.4, 117.7, 121.3, 122.8, 126.4, 127.7, 128.2, 128.6, 129.0, 133.5, 133.8, 134.1, 134.6, 139.9, 163.6, 175.5, 180.5. MS m/z (%) 319 (M^+, 97), 274 (100), 247 (97), 190 (42), 139 (4). Anal. Calcd for $C_{19}H_{13}NO_4$: C, 71.47; H, 4.08; N, 4.39. Found: C, 71.66; H, 4.16; N, 4.40.

4.2.6. 12-Cyanobenzo[*f*]pyrido[1,2-*a*]indole-6,11-dione (15c). Yield: 58%; red solid from petroleum ether (bp 60–90 °C)/chloroform; mp >300 °C (lit.[29] 307.5–308.5 °C). IR (KBr) ν 3139, 3114, 3083, 3034, 2221, 1668, 1644, 1628, 1596, 1508, 1388, 1232, 746, 711 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 7.29 (d, 1H, J=7.0 Hz), 7.57 (t, 1H, J=8.7 Hz), 7.75–7.84 (m, 2H), 7.96 (d, 1H, J=9.0 Hz), 8.27–8.30 (m, 2H), 9.77 (d, 1H, J=7.0 Hz). MS m/z (%) 272 (M^+, 100), 244 (5), 216 (18), 188 (6), 108 (7), 78 (11). Anal. Calcd for $C_{17}H_8N_2O_2$: C, 75.00; H, 2.94; N, 10.29. Found: C, 74.89; H, 2.99; N, 10.25.

4.3. Syntheses of 11, 12, and 16; general procedure

A mixture of an isoquinoline salt (**2a**–**2d**, 1.1 mmol), a dichloro substituted α,β-unsaturated carbonyl compounds (**4**, **6**, and **7**, 1 mmol), and potassium carbonate (0.48 g, 3.5 mmol) in MeCN (15 ml) was heated at 50 °C for 24 h with magnetic stirring. The reaction was monitored by TLC. The solvent was removed under reduced pressure, and the residue was separated by flash chromatography on a silica gel column with petroleum ether (bp 60–90 °C)/ethyl acetate as an eluent to give the corresponding products **11**, **12**, and **16**.

4.3.1. 8-Benzoyl-13*H*-indeno[2′,1′:3,4]pyrrolo[2,1-*a*]isoquinolin-13-one (11a). Yield: 50%; yellow solid from petroleum ether (bp 60–90 °C)/chloroform; 183–185 °C. IR (KBr) ν 3053, 2921, 2851, 1683, 1616, 1599, 1541, 1522, 1375, 1347, 1172, 906, 795, 734, 717, 698 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 6.97 (t, 1H, J=7.5 Hz), 7.12–7.19 (m, 2H), 7.54–7.74 (m, 8H), 7.96 (d, 2H, J=7.2 Hz), 9.02 (d, 1H, J=7.5 Hz), 9.50 (d, 1H, J=8.5 Hz). MS m/z (%) 373 (M^+, 100), 344 (24), 296 (16), 268 (16), 77 (16). Anal. Calcd for $C_{26}H_{15}NO_2$: C, 83.65; H, 4.02; N, 3.75. Found: C, 83.63; H, 4.03; N, 3.77.

4.3.2. 8-Ethoxycarbonyl-13*H*-indeno[2′,1′:3,4]pyrrolo-[2,1-*a*]isoquinolin-13-one (11b). Yield: 45%; yellow solid from petroleum ether (bp 60–90 °C)/chloroform; mp 196–198 °C. IR (KBr) ν 2924, 2853, 1685, 1638, 1602, 1557, 1528, 1459, 1381, 1357, 1066, 798, 723 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 1.58 (t, 3H, J=7.2 Hz), 4.58 (q, 2H, J=7.2 Hz), 7.10 (d, 1H, J=7.6 Hz), 7.32 (t, 1H, J=7.5 Hz), 7.45 (t, 1H, J=7.5 Hz), 7.66–7.69 (m, 4H), 8.00 (d, 1H, J=7.6 Hz), 9.23 (d, 1H, J=7.6 Hz), 9.43 (d, 1H, J=7.9 Hz). MS m/z (%) 341 (M^+, 100), 313 (37), 269 (39), 240 (34), 213 (14), 149 (10), 57 (21), 44 (50). Anal. Calcd for $C_{22}H_{15}NO_3$: C, 77.42; H, 4.40; N, 4.11. Found: C, 77.38; H, 4.37; N, 4.13.

4.3.3. 8-Acetyl-13*H*-indeno[2′,1′:3,4]pyrrolo[2,1-*a*]isoquinolin-13-one (11c). Yield: 50%; yellow solid from petroleum ether (bp 60–90 °C)/chloroform; mp 156–158 °C. IR (KBr) ν 3051, 2922, 1679, 1643, 1599, 1534, 1518, 1487,

1369, 1184, 799, 725 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 2.91 (s, 3H), 7.14 (d, 1H, J=7.6 Hz), 7.37 (t, 1H, J=7.4 Hz), 7.49 (td, 1H, J=7.6 Hz, 1.3 Hz), 7.71–7.76 (m, 4H), 7.82 (d, 1H, J=7.7 Hz), 9.48 (d, 1H, J=7.7 Hz), 9.56–9.59 (m, 1H). MS *m*/*z* (%) 311 (M^+, 28), 296 (24), 240 (10), 213 (4), 127 (3), 43 (100). Anal. Calcd for $C_{21}H_{13}NO_2$: C, 81.03; H, 4.18; N, 4.50. Found: C, 81.08; H, 4.15; N, 4.53.

4.3.4. 8-Cyano-13*H*-indeno[2′,1′:3,4]pyrrolo[2,1-*a*]isoquinolin-13-one (11d). Yield: 46%; yellow solid from petroleum ether (bp 60–90 °C)/chloroform; mp 288–290 °C. IR (KBr) ν 3073, 2963, 2210, 1689, 1604, 1573, 1523, 1487, 1360, 1261, 1099, 791, 723 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 7.21 (d, 1H, J=7.5 Hz), 7.38 (t, 1H, J=7.5 Hz), 7.51 (t, 1H, J=7.4 Hz), 7.63 (t, 1H, J=7.5 Hz), 7.69–7.79 (m, 4H), 8.01 (d, 1H, J=7.3 Hz), 9.26 (d, 1H, J=7.8 Hz). MS *m*/*z* (%) 294 (M^+, 100), 265 (21), 213 (5), 133 (10), 44 (25). Anal. Calcd for $C_{20}H_{10}N_2O$: C, 81.63; H, 3.40; N, 9.52. Found: C, 81.66; H, 3.46; N, 9.50.

4.3.5. 8-Benzoyl-9a,13a-dichloro-9a,10,13,13a-tetrahydro-10,13-methanobenz[5,6]isoindolo[1,2-*a*]isoquinoline-9,14-dione (12a). CCDC No. 602716. Yield: 82%; white solid from petroleum ether (bp 60–90 °C)/acetone; mp >300 °C. IR (KBr) ν 3125, 2957, 1698, 1672, 1638, 1596, 1578, 1551, 1503, 1426, 1351, 1248, 1223, 1148, 949, 798, 736, 702 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 2.01 (d, 1H, J=10.0 Hz), 2.52 (d, 1H, J=10.0 Hz), 3.47 (s, 1H), 3.76 (s, 1H), 6.04–6.07 (m, 1H), 6.17–6.20 (m, 1H), 7.37 (d, 1H, J=7.5 Hz), 7.50 (t, 2H, J=7.6 Hz), 7.61–7.81 (m, 4H), 8.02 (dd, 2H, J=7.6 Hz, 1.4 Hz), 8.74 (d, 1H, J=7.5 Hz), 9.49–9.53 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 44.9, 54.5, 55.0, 79.6, 115.3, 119.0, 123.9, 124.7, 125.3, 127.5, 127.6, 129.0, 129.3, 129.8, 130.5, 130.9, 134.0, 135.7, 137.7, 138.3, 138.5, 185.0, 185.4, 187.6. MS *m*/*z* (%) 419 (23), 356 (8), 264 (4), 188 (18), 164 (6), 105 (26), 77 (100). Anal. Calcd for $C_{28}H_{17}NO_3Cl_2$: C, 69.28; H, 3.51; N, 2.89. Found: C, 69.27; H, 3.57; N, 2.89.

4.3.6. 8-Ethoxycarbonyl-9a,13a-dichloro-9a,10,13,13a-tetrahydro-10,13-methanobenz[5,6]*iso*-indolo[1,2-*a*]isoquinoline-9,14-dione (12b). Yield: 83%; yellow solid from petroleum ether (bp 60–90 °C)/chloroform; mp 228–230 °C. IR (KBr) ν 3131, 2980, 1709, 1677, 1551, 1537, 1504, 1471, 1257, 1213, 1103, 804, 699 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 1.43 (t, 3H, J=7.1 Hz), 2.10 (d, 1H, J=9.8 Hz), 2.58 (d, 1H, J=9.8 Hz), 3.66 (d, 1H, J=1.7 Hz), 3.74 (d, 1H, J=1.7 Hz), 4.43–4.54 (m, 2H), 6.26–6.27 (m, 2H), 7.38 (d, 1H, J=7.5 Hz), 7.71–7.81 (m, 3H), 9.18 (d, 1H, J=7.5 Hz), 9.47 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 14.2, 45.1, 54.2, 54.7, 78.5, 80.0, 115.9, 117.1, 118.5, 123.9, 125.1, 127.2, 127.4, 129.1, 129.9, 130.6, 134.6, 138.1, 138.9, 160.7, 184.8, 185.0. MS *m*/*z* (%) 453 (M^+, 14), 418 (21), 387 (100), 315 (81), 252 (81), 240 (52), 188 (87), 164 (53), 66 (89). Anal. Calcd for $C_{24}H_{17}NO_4Cl_2$: C, 63.58; H, 3.75; N, 3.09. Found: C, 63.55; H, 3.76; N, 3.10.

4.3.7. 8-Acetyl-9a,13a-dichloro-9a,10,13,13a-tetrahydro-10,13-methanobenz[5,6]isoindolo[1,2-*a*]isoquinoline-9,14-dione (12c). Yield: 90%; yellow solid from petroleum ether (bp 60–90 °C)/chloroform; mp 238–240 °C. IR (KBr) ν 3141, 3003, 2956, 1702, 1686, 1660, 1548, 1502, 1474, 1364, 1148, 803, 696 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 2.14 (d, 1H, J=10.0 Hz), 2.58 (d, 1H, J=10.0 Hz), 2.75 (s, 3H), 3.67 (s, 1H), 3.76 (s, 1H), 6.28 (s, 2H), 7.40 (d, 1H, J=7.6 Hz), 7.72–7.76 (m, 2H), 7.79–7.82 (m, 1H), 9.38 (d, 1H, J=7.5 Hz), 9.41–9.45 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 30.3, 45.1, 54.1, 54.6, 78.8, 79.6, 116.0, 119.1, 124.3, 124.7, 124.9, 127.3, 127.4, 129.2, 130.5, 130.9, 134.9, 138.4, 138.7, 184.9, 186.5, 192.1. MS *m*/*z* (%): 423 (M^+, 18), 357 (93), 329 (80), 252 (42), 224 (34), 188 (65), 128 (20), 66 (100), 43 (72). Anal. Calcd for $C_{23}H_{15}NO_3Cl_2$: C, 65.25; H, 3.55; N, 3.31. Found: C, 65.21; H, 3.58; N, 3.28.

4.3.8. 8-Cyano-9a,13a-dichloro-9a,10,13,13a-tetrahydro-10,13-methanobenz[5,6]isoindolo[1,2-*a*]isoquinoline-9,14-dione (12d). Yield: 85%; yellow solid from petroleum ether (bp 60–90 °C)/chloroform; mp >300 °C. IR (KBr) ν 3142, 2950, 2228, 1699, 1671, 1548, 1502, 1465, 1439, 1234, 1146, 793, 697 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 2.12 (d, 1H, J=10.0 Hz), 2.61 (d, 1H, J=10.0 Hz), 3.76 (d, 1H, J=1.7 Hz), 3.80 (d, 1H, J=1.7 Hz), 6.21–6.23 (m, 2H), 7.56 (d, 1H, J=7.2 Hz), 7.81–7.91 (m, 3H), 8.29 (d, 1H, J=7.2 Hz), 9.58–9.61 (m, 1H). MS *m*/*z* (%) 406 (M^+, 5), 371 (7), 340 (100), 277 (81), 249 (35), 163 (39), 105 (41), 66 (97), 44 (83). Anal. Calcd for $C_{22}H_{12}N_2O_2Cl_2$: C, 65.02; H, 2.96; N, 6.90. Found: C, 65.06; H, 2.93; N, 6.88.

4.3.9. 8,13-Dihydro-14-benzoylbenz[5,6]indolo[2,1-*a*]isoquinoline-8,13-dione (16a). Yield: 76%; yellow solid from petroleum ether/chloroform; mp >300 °C (lit.[29] 307.5–308.5 °C). IR (KBr) ν 3126, 3055, 1665, 1657, 1645, 1593, 1505, 1393, 1236, 1221, 957, 792, 706 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 7.36 (d, 1H, J=7.5 Hz), 7.45–7.69 (m, 6H), 7.76 (t, 2H, J=7.9 Hz), 7.94 (d, 1H, J=8.1 Hz), 8.08 (d, 3H, J=7.5 Hz), 8.29 (d, 1H, J=7.5 Hz), 9.54 (d, 1H, J=7.5 Hz). MS *m*/*z* (%) 401 (M^+, 50), 372 (6), 324 (100), 240 (22), 149 (9), 105 (8), 77 (21). Anal. Calcd for $C_{27}H_{15}NO_3$: C, 80.80; H, 3.74; N, 3.49. Found: C, 80.72; H, 3.78; N, 3.43.

4.3.10. 8,13-Dihydro-14-ethoxycarbonylbenz[5,6]indolo[2,1-*a*]isoquinoline-8,13-dione (16b). Yield: 78%; yellow solid from petroleum ether (bp 60–90 °C)/chloroform; mp 238–240 °C (lit.[29] 239–239.5 °C). IR (KBr) ν 3149, 3060, 2985, 2950, 1724, 1661, 1644, 1611, 1592, 1571, 1506, 1390, 1232, 1224, 1199, 952, 798, 704 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 1.56 (t, 3H, J=7.1 Hz), 4.70 (q, 2H, J=7.1 Hz), 7.33 (d, 1H, J=7.3 Hz), 7.63–7.81 (m, 5H), 8.23 (dd, 1H, J=7.9 Hz, 1.8 Hz), 8.27–8.32 (m, 2H), 9.49 (d, 1H, J=7.4 Hz). ^{13}C NMR ($CDCl_3$) δ: 14.5, 62.8, 110.6, 117.8, 124.7, 124.8, 126.9, 127.2, 128.0, 129.3, 129.7, 129.9, 133.0, 133.6, 133.9, 134.1, 134.8, 167.0, 175.6, 181.0. MS *m*/*z* (%) 369 (M^+, 72), 324 (78), 297 (100), 240 (52), 213 (17), 119 (7), 76 (9), 44 (17). Anal. Calcd for $C_{23}H_{15}NO_4$: C, 74.80; H, 4.07; N, 3.80. Found: C, 74.79; H, 4.12; N, 3.80.

4.3.11. 8,13-Dihydro-14-acetylbenz[5,6]indolo[2,1-*a*]isoquinoline-8,13-dione (16c). CCDC No. 616322. Yield: 85%; yellow solid from petroleum ether (bp 60–90 °C)/chloroform; mp 281–283 °C (lit.[29] 281–282 °C). IR (KBr) ν 3126, 3068, 2989, 1701, 1658, 1644, 1594, 1574, 1530, 1505, 1482, 1393, 1361, 1285, 1233, 1184, 956, 703 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$) δ: 2.90 (s, 3H), 7.31 (d, 1H, J=7.5 Hz), 7.62–7.79 (m, 5H), 8.20–8.27 (m, 2H), 8.28 (dd, 1H, J=7.9 Hz, 1.8 Hz), 9.50 (d, 1H, J=7.5 Hz). MS m/z (%) 339 (M^+, 55), 324 (100), 310 (6), 240 (29), 213 (8), 120 (6), 55 (9), 44 (54). Anal. Calcd for $C_{22}H_{13}NO_3$: C, 77.88; H, 3.83; N, 4.13. Found: C, 77.85; H, 3.85; N, 4.11.

4.3.12. 8,13-Dihydro-14-cyanobenz[5,6]indolo[2,1-*a*]isoquinoline-8,13-dione (16d). Yield: 70%; yellow solid from petroleum ether/chloroform; mp >300 °C (lit.[29] 350–350.5 °C). IR (KBr) ν 3126, 3091, 2219, 1672, 1643, 1596, 1585, 1551, 1519, 1479, 1387, 1264, 1233, 953, 813, 721, 685 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.47 (d, 1H, J=7.6 Hz), 7.79–7.87 (m, 5H), 8.29–8.34 (m, 2H), 9.16 (d, 1H, J=7.3 Hz), 9.53 (d, 1H, J=7.3 Hz). MS m/z (%) 322 (M^+, 100), 298 (9), 238 (26), 213 (6), 171 (8), 128 (15), 91 (23), 44 (99). Anal. Calcd for $C_{21}H_{10}N_2O_2$: C, 78.26; H, 3.11; N, 8.70. Found: C, 78.32; H, 3.13; N, 8.72.

4.4. Syntheses of 13, 14, and 17; general procedure

A mixture of quinoline ylide (**3a**–**3c**, 1.1 mmol), dichloro substituted α,β-unsaturated carbonyl compounds (**4** and **6**–**8**, 1 mmol), and potassium carbonate (0.48 g, 3.5 mmol) in MeCN (15 ml) was heated at 50 °C for 24 h with magnetic stirring. The reaction was monitored by TLC. The solvent was removed under reduced pressure, and the residual solid was separated by flash chromatography on a silica gel column with petroleum ether (bp 60–90 °C)—ethyl acetate as an eluent to give the products **13**, **14**, and **17**.

4.4.1. 12-Benzoyl-7*H*-indeno[2′,1′:3,4]pyrrolo[2,1-*a*]quinolin-7-one (13a). CCDC No. 602715. Yield: 40%; yellow solid from petroleum ether (bp 60–90 °C)/chloroform; mp 242–243 °C. IR (KBr) ν 3061, 1692, 1635, 1625, 1606, 1564, 1551, 1516, 1476, 1448, 1339, 1198, 957, 894, 809, 726, 712, 690 cm^{-1}. ^{1}HNMR (300 MHz, $CDCl_3$) δ: 6.08 (d, 1H, J=7.5 Hz), 7.06 (td, 1H, J=7.5 Hz, 1.2 Hz), 7.18 (t, 1H, J=7.5 Hz), 7.28–7.46 (m, 2H), 7.56–7.64 (m, 3H), 7.72–7.77 (m, 2H), 7.82 (d, 1H, J=9.1 Hz), 8.16 (dd, 2H, J=8.8 Hz, 1.3 Hz). MS m/z (%) 373 (M^+, 100), 344 (35), 317 (41), 296 (44), 268 (19), 240 (70), 187 (12), 105 (29), 77 (66). Anal. Calcd for $C_{26}H_{15}NO_2$: C, 83.65; H, 4.02; N, 3.75. Found: C, 83.58; H, 4.09; N, 3.78.

4.4.2. 12-Ethoxycarbonyl-7*H*-indeno[2′,1′:3,4]pyrrolo[2,1-*a*]quinolin-7-one (13b). Yield: 28%; yellow solid from petroleum ether (bp 60–90 °C)/chloroform; mp 193–195 °C. IR (KBr) ν 3124, 2977, 1705, 1688, 1622, 1607, 1573, 1552, 1445, 1296, 1170, 810, 754, 723 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.54 (t, 3H, J=7.2 Hz), 4.61 (q, 2H, J=7.2 Hz), 7.31 (t, 1H, J=7.5 Hz), 7.46 (t, 2H, J=7.5 Hz), 7.58–7.66 (m, 3H), 7.76 (d, 2H, J=9.0 Hz), 7.93 (t, 2H, J=7.0 Hz). MS m/z (%) 341 (M^+, 73), 313 (23), 269 (100), 240 (47), 213 (13), 163 (5), 129 (7), 57 (19), 44 (24). Anal. Calcd for $C_{22}H_{15}NO_3$: C, 77.42; H, 4.40; N, 4.11. Found: C, 77.33; H, 4.47; N, 4.15.

4.4.3. 12-Acetyl-7*H*-indeno[2′,1′:3,4]pyrrolo[2,1-*a*]quinolin-7-one (13c). Yield: 30%; yellow solid from petroleum ether (bp 60–90 °C)/chloroform; mp 223–225 °C. IR (KBr) ν 1684, 1665, 1618, 1602, 1567, 1548, 1474, 1447, 1336, 1143, 814, 754, 726 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 2.56 (s, 3H), 7.33 (td, 1H, J=7.5 Hz, 0.9 Hz), 7.43–7.52 (m, 2H), 7.54–7.69 (m, 4H), 7.77–7.87 (m, 3H). MS m/z (%) 311 (M^+, 48), 296 (62), 240 (30), 213 (13), 188 (6), 76 (17), 43 (100). Anal. Calcd for $C_{21}H_{13}NO_2$: C, 81.03; H, 4.18; N, 4.50. Found: C, 81.00; H, 4.25; N, 4.48.

4.4.4. 13-Benzoyl-7a,11a-dichloro-7a,8,11,11a-tetrahydro-8,11-methanobenz[5,6]isoindolo[1,2-*a*]quinoline-7,12-dione (14a). Yield: 65%; white solid from petroleum ether (bp 60–90 °C)/chloroform; mp >300°C. IR (KBr) ν 3125, 3086, 2957, 1698, 1672, 1638, 1596, 1578, 1551, 1503, 1426, 1351, 1248, 1223, 949, 887, 798, 702 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 2.02 (d, 1H, J=9.9 Hz), 2.52 (d, 1H, J=9.9 Hz), 3.52 (br, 1H), 3.74 (br, 1H), 6.06–6.08 (m, 1H), 6.15–6.18 (m, 1H), 7.51–7.67 (m, 4H), 7.70–7.79 (m, 2H), 7.88 (dd, 1H, J=9.1 Hz, 1.7 Hz), 8.18 (dd, 1H, J=8.1 Hz, 1.3 Hz), 8.38 (d, 1H, J=9.3 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 45.7, 55.5, 55.9, 78.4, 79.3, 118.7, 119.1, 126.5, 127.4, 127.9, 129.5, 130.0, 130.1, 130.2, 130.3, 132.6, 135.2, 136.3, 137.2, 137.6, 138.4, 185.6, 186.2, 189.6. Anal. Calcd for $C_{28}H_{17}NO_3Cl_2$: C, 69.28; H, 3.51; N, 2.89. Found: C, 69.32; H, 3.48; N, 2.90.

4.4.5. 13-Acetyl-7a,11a-dichloro-7a,8,11,11a-tetrahydro-8,11-methanobenz[5,6]isoindolo[1,2-*a*]quinoline-7,12-dione (14c). Yield: 60%; white solid from petroleum ether (bp 60–90 °C)/chloroform; mp 199–200 °C. IR (KBr) ν 3077, 2958, 1692, 1670, 1616, 1606, 1550, 1495, 1440, 1361, 1181, 1155, 814, 760, 727, 704, 697 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 2.08 (d, 1H, J=9.9 Hz), 2.59 (d, 1H, J=9.9 Hz), 2.93 (s, 3H), 3.69 (br, 1H), 3.75 (br, 1H), 6.15–6.20 (m, 2H), 7.60–7.67 (m, 4H), 7.88 (dd, 1H, J=7.6 Hz, 1.7 Hz), 8.31 (d, 1H, J=9.9 Hz). MS m/z (%) 425 (M^++2, 1), 423 (M^+, 1), 358 (100), 344 (73), 328 (31), 289 (14), 224 (28), 188 (25), 66 (57), 43 (17). Anal. Calcd for $C_{23}H_{15}NO_3Cl_2$: C, 65.25; H, 3.55; N, 3.31. Found: C, 65.35; H, 3.62; N, 3.36.

4.4.6. 7-Benzoylbenz[5,6]indolo[1,2-*a*]quinoline-8,13-dione (17a). Yield: 60%; yellow solid from petroleum ether (bp 60–90 °C)/chloroform; mp 285–286 °C. IR (KBr) ν 3060, 1666, 1656, 1642, 1595, 1556, 1500, 1390, 1243, 960, 800, 718 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.41–7.57 (m, 5H), 7.67–7.79 (m, 4H), 7.85 (d, 1H, J=7.5 Hz), 8.11 (d, 3H, J=7.5 Hz), 8.35 (d, 1H, J=7.5 Hz), 8.50 (d, 1H, J=7.5 Hz). MS m/z (%) 401 (M^+, 100), 324 (43), 297 (10), 240 (22), 149 (9), 105 (27), 77 (55). Anal. Calcd for $C_{27}H_{15}NO_3$: C, 80.80; H, 3.74; N, 3.49. Found: C, 80.86; H, 3.80; N, 3.42.

4.4.7. 8,13-Dihydro-7-ethoxycarbonylbenz[5,6]indolo[1,2-*a*]quinoline-8,13-dione (17b). Yield: 42%; yellow solid from petroleum ether (bp 60–90 °C)/chloroform; mp 219–220 °C. IR (KBr) ν 3061, 2963, 1723, 1666, 1645, 1618, 1591, 1556, 1536, 1482, 1441, 1292, 1241, 1195, 960, 804, 719 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.55 (t, 3H, J=7.2 Hz), 4.74 (q, 2H, J=7.2 Hz), 7.56–7.67 (m, 3H), 7.73–7.76 (m, 2H), 7.86 (d, 1H, J=8.0 Hz), 7.97 (d, 1H, J=8.3 Hz), 8.27 (d, 1H, J=7.5 Hz), 8.33 (d, 1H, J=7.5 Hz), 8.45 (d, 1H, J=9.4 Hz). MS m/z (%) 369 (M^+, 39), 324 (18), 297 (100), 240 (46), 213 (12), 128 (5), 44 (17). Anal. Calcd for $C_{23}H_{15}NO_4$: C, 74.80; H, 4.07; N, 3.80. Found: C, 74.76; H, 4.04; N, 3.82.

4.4.8. 8,13-Dihydro-7-acetylbenz[5,6]indolo[1,2-*a*]quinoline-8,13-dione (17c). Yield: 45%; yellow solid from petroleum ether (bp 60–90 °C)/chloroform; mp 278–280 °C (lit.[29] 278.5–279.0 °C). IR (KBr) ν 3061, 2921, 1685, 1665, 1649, 1637, 1619, 1609, 1552, 1502, 1440, 1264, 1243, 1148, 1085, 960, 760, 722, 711 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 3.06 (s, 3H), 7.57–7.68 (m, 3H), 7.74–7.81 (m, 3H), 7.86 (dd, 1H, J=9.0 Hz, 1.7 Hz), 8.25 (dd, 1H, J=9.0 Hz, 1.7 Hz), 8.33 (dd, 1H, J=9.0 Hz, 1.7 Hz), 8.48 (d, 1H, J=9.3 Hz). MS *m/z* (%) 339 (M^+, 100), 324 (94), 296 (45), 240 (68), 213 (21), 164 (13), 120 (9), 76 (19), 43 (30). Anal. Calcd for $C_{22}H_{13}NO_3$: C, 77.88; H, 3.83; N, 4.13. Found: C, 77.80; H, 3.88; N, 4.11.

Acknowledgements

This work was supported by the NSFC (20772024). Partial support from the Modern Analytical Center and Institute of Theoretical and Computational Chemistry at Nanjing University is also gratefully acknowledged.

Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tet.2006.12.050.

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