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Chlorophyll-Catalyzed Visible-Light-Mediated Synthesis of Tetrahydroquinolines from *N,N*-Dimethylanilines and Maleimides

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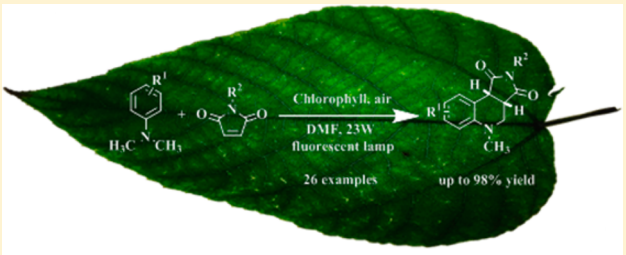
Supporting Information

ABSTRACT: Natural pigment chlorophyll was used as a green photosensitizer for the first time in a visible-light photoredox catalysis for the efficient synthesis of tetrahydroquinolines from *N,N*-dimethylanilines and maleimides in an air atmosphere. The reaction involves direct cyclization via an sp^3 C−H bond functionalization process to afford products in moderate to high yields (61−98%) from a wide range of substrates with a low loading of chlorophyll under mild conditions. This work demonstrates the potential benefits of chlorophyll as photosensitizer in visible light catalysis.



1. INTRODUCTION

Light is an inexpensive, abundant, and endlessly renewable source of clean energy.[1] Thus, visible light photoredox catalysis as an effective and versatile method has become a powerful and promising tool. It has been productively used to drive chemical transformations in the field of organic synthesis.[2] Since photoinduced electron transfer (PET) reactions can be used to construct molecular architectures that would otherwise be difficult to produce, photochemistry would significantly impact multiple aspects of chemical synthesis.[3]

Photosynthesis is one of the most famous chemical reactions in nature in which plants use sunlight as their energy source to convert CO_2 and H_2O to sugars. Chlorophyll is the most abundant natural visible light photocatalyst on the earth. It is the principal photoacceptor in the chloroplasts of most green plants. In 2015, Boyer et al. utilized the electron transfer mechanism of chlorophyll under light to control radical polymerization.[4] As a green, environmentally friendly and widespread photosensitizer, chlorophyll has been rarely applied in photodriven synthesis. Inspired by the leading role of chlorophyll in photosynthesis, we envisaged that it may be possible to use chlorophyll as a highly efficient photosensitizer in visible-light catalysis for organic synthesis.

The tetrahydroquinoline moiety is an important structural feature of various natural products and pharmaceutical agents that have exhibited a broad range of biological activities such as antibacterial, neuroprotectant, antiarrhythmic etc.[5] Owing to their ubiquitous distribution in natural products and medicinal agents, tetrahydroquinolines have become important synthetic targets for chemists.[6] In 2011, Miura et al.[7] used $CuCl_2/O_2$ to catalyze *N*-methylanilines and maleimides for the synthesis of the tetrahydroquinolines in moderate yields. Because tertiary amines have low oxidation potentials, many reported PET processes make use of these molecules as electron donors.[8] The photoredox reactions were also employed to develop the tetrahydroquinolines using tertiary amines and maleimides. $Ru(bpy)_3Cl_2$,[9] Eosin Y,[10] TiO_2,[11] $[Cu(dap)_2]Cl$,[12] and conjugated nanoporous polymers[13] have been used as photosensitizers in the visible-light-mediated photoredox reactions for the synthesis of tetrahydroquinoline derivatives.

Herein, we report the first example of natural pigment chlorophyll being used as a green and efficient photosensitizer in a visible-light photoredox catalysis for the synthesis of tetrahydroquinolines from *N,N*-dimethylanilines and maleimides in an air atmosphere. This work demonstrated that chlorophyll can act as a visible-light photoredox catalyst to initiate organic transformations. This novel process provides an example for exploring environmentally friendly, simple and convenient synthetic route utilizing chlorophyll and light energy in organic chemistry.

2. RESULTS AND DISCUSSION

Initially, the cyclization reaction between *N,N*-dimethyl-*p*-toluidine (**1a**, 0.50 mmol) and *N*-phenylmaleimide (**2a**, 0.25 mmol) in DMF (1.0 mL) under an air atmosphere (with no air bubbling) was chosen as the model reaction system. First, key control experiments were performed to establish that both visible light and chlorophyll are necessary for the reaction. Without visible light and chlorophyll no reaction was observed (Table 1, entry 1). The reaction in the absence of either visible light or chlorophyll only gave a trace amount of product (Table 1, entries 2 and 3). Gratifyingly, when the model reaction was carried out with 0.16 mg of chlorophyll (30 mg of chlorophyll powder preparation, in which total chlorophyll content is 0.52%) under irradiation with a 23 W fluorescent lamp, the

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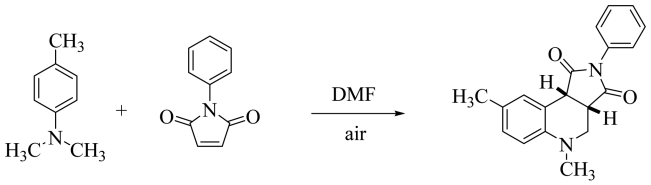
Table 1. Control Experiments[a]



1a 2a 3a

entry	visible light (irradiation with a 23 W fluorescent lamp)	chlorophyll (0.16 mg)	TEMPO (0.50 mmol)	yield[b] (%)
1	–[c]	–	–	no reaction
2	+[d]	–	–	trace
3	–	+	–	trace
4	+	+	–	80
5[e]	+	+	–	8
6	+	+	+	trace

[a]Reaction conditions: a mixture of **1a** (0.50 mmol) and **2a** (0.25 mmol) in DMF (1.0 mL) was stirred for 36 h. [b]Yield of the isolated product after silica gel chromatography. [c]"–" means the corresponding substance was not used. [d]"+" means the corresponding substance was used. [e]Nitrogen protection without oxygen.

desired product tetrahydroquinoline **3a** was obtained with 80% yield after 36 h (Table 1, entry 4). The results indicated that both visible light and chlorophyll are necessary for the model reaction. In order to check if oxygen is necessary in this reaction, the model reaction was conducted in the absence of oxygen under nitrogen, and product **3a** was only obtained in a low yield of 8% (Table 1, entry 5). This result indicated that oxygen plays a key role in this reaction. Furthermore, to verify if a radical process is involved in this reaction, a test experiment was performed with a free-radical scavenger, (2,2,6,6-tetramethylpiperidin-1-yl)oxidanyl (TEMPO). Only a trace amount of product **3a** was observed when TEMPO was added to the model reaction (Table 1, entry 6), indicating the involvement of a radical mechanism.

It is well-known that chlorophyll can generate singlet oxygen upon irradiation in oxygenated solution.[14] In order to verify the existence of singlet oxygen, we did some control experiments under optimal reaction conditions (details of the optimizations were described hereafter in Table 3 and Table S1). When 0.25 mmol (1 equiv) of 1,4-diazabicyclo[2.2.2]octane (DABCO), which is known as a quencher of singlet oxygen,[15] was added to the model reaction, no product **3a** was observed within the first 18 h. The reaction rate was largely suppressed during the reaction time. A much lower yield of 12% was obtained in the presence of DABCO after 48 h compared to the yield of 97% (under optimal reaction conditions) without DABCO (Figure 1). The results suggested that singlet oxygen must be involved in the reaction mechanism.

The natural pigment chlorophyll we used was purchased from Tokyo Chemical Industry (TCI). This is a mixture powder of chlorophyll, lactose, and dry gum arabic, in which the total chlorophyll from plants is 0.52% (the mass percentage) (for more information about this chlorophyll preparation, see the Supporting Information). In order to exclude the effects of lactose and dry gum arabic on the model reaction, some comparison experiments were performed. In the model reaction described in Table 1, entry 4, 0.16 mg of chlorophyll (30 mg of chlorophyll powder preparation, in which total chlorophyll content is 0.52%) was used. Thus, as a

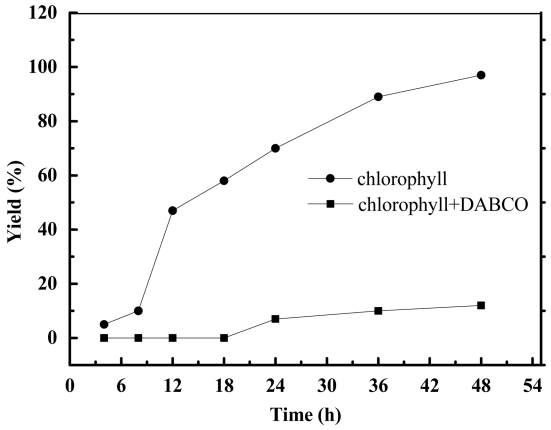


Figure 1. Influence of DABCO on the model reaction.

comparison, lactose (30 mg), gum arabic (30 mg), and lactose/gum arabic = 1/1 mixture (30 mg) were used instead of chlorophyll to catalyze the reaction, respectively. It can be seen that lactose, gum arabic, and the mixture of lactose and gum arabic displayed a low degree of catalytic effect on the model reaction, giving **3a** with a yield ranging from 7 to 28% (Table 2, entries 1, 4, and 7). To understand this phenomenon, we performed some control experiments. First, we measured the visible-light absorption of gum arabic and lactose and found that none of them showed obvious absorption in the visible light range (for details, see Figures S2 and S3). Next, when a free-radical scavenger, (2,2,6,6-tetramethylpiperidin-1-yl)-oxidanyl (TEMPO) (2 equiv) (Table 2, entries 2, 5, and 8), and a singlet oxygen quencher, 1,4-diazabicyclo[2.2.2]octane (DABCO) (1 equiv) (Table 2, entries 3, 6, and 9), were added into the reaction system separately, only a trace amount of product **3a** was observed. On the basis of the above results, we can draw the conclusion that the additives (lactose and gum arabic) in commercial chlorophyll preparation can catalyze the model reaction; a free-radical process and singlet oxygen may be involved in these reactions. However, the catalysis degree of these additives was much lower than that of chlorophyll. The results confirmed that chlorophyll plays a leading role in this photocatalytic reaction. Chlorophyll a is the most distributed form of chlorophyll in plants, and its structure is shown in Figure 2.

Next, we optimized the reaction conditions with respect to solvents and catalyst dosages. DMF was found to be the best solvent among DMF, DMSO, MeCN, MeOH, THF, DCM, and H_2O (Table 3, entries 1–7). Then the catalyst dosage was screened. When the amount of chlorophyll was increased from 0.05 to 0.16 mg, the yield of product **3a** increased significantly (Table 3, entries 1, 8, and 9). When the amount of chlorophyll was further increased from 0.16 to 0.21 mg, the yield of **3a** remained almost unchanged (Table 3, entries 1 and 10). Therefore, DMF and 0.16 mg of catalyst dosage were chosen as suitable conditions for the model reaction. Additionally, the influences of molar ratio, solvent volume, lamp wattage, and reaction time were investigated. On the basis of the experimental results, **1a**/**2a** = 2:1, 2.0 mL of DMF and 23 W fluorescent lamp were chosen as the optimum conditions for the model reaction (for details, see Table S1).

With the optimized conditions in hand, the substrate scope of this photoreaction was investigated (Table 4). A series of *N*,*N*-dimethylanilines **1** with a range of substituents on the benzene ring and maleimides **2** with different substituents on

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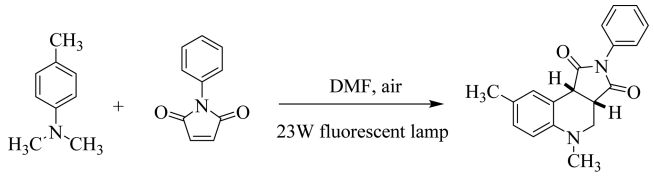
Table 2. Comparison Experiments[a]



1a **2a** **3a**

entry	lactose (30 mg)	gum arabic (30 mg)	lactose/gum arabic =1/1 mixture (30 mg)	TEMPO (0.50 mmol)	DABCO (0.25 mmol)	yield[b] (%)
1	–[c]	+[d]	–	–	–	28
2	–	+	–	+	–	trace
3	–	+	–	–	+	trace
4	+	–	–	–	–	7
5	+	–	–	+	–	trace
6	+	–	–	–	+	trace
7	–	–	+	–	–	19
8	–	–	+	+	–	trace
9	–	–	+	–	+	trace

[a]Reaction conditions: a mixture of **1a** (0.50 mmol) and **2a** (0.25 mmol) in DMF (1.0 mL) was irradiated with a 23 W fluorescent lamp for 36 h. [b]Yield of the isolated product after silica gel chromatography. [c]"–" means the corresponding substance was not used. [d]"+" means the corresponding substance was used.

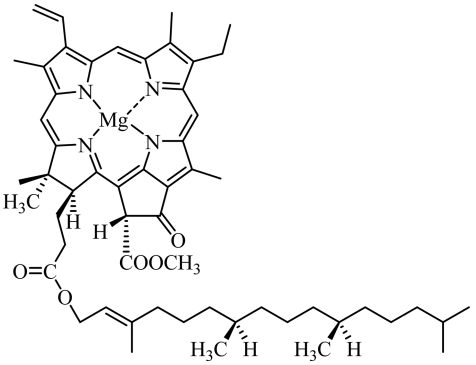
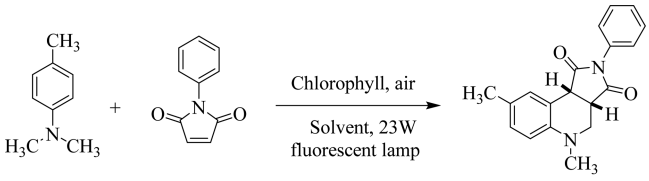


Figure 2. Structure of chlorophyll a.

the N atom were examined. It can be seen that *N*,*N*-dimethylanilines with either electron-donating groups (4-Me) or electron-withdrawing groups (4-F, 4-Cl, 4-Br) reacted well with *N*-alkylmaleimides and *N*-arylmaleimides to give the corresponding products in good yields (Table 4, entries 1–3, 5–9, 11–24, and 26). When the *N*-*tert*-butyl maleimide was used, relatively low yields (61–66%) (Table 4, entries 4, 10, and 25) were obtained after 48 h; this is probably due to the larger steric hindrance. The highest yield of 98% was achieved (Table 4, entries 13 and 17). Thirteen new tetrahydroquinoline derivatives were obtained, and their structures were confirmed by HRMS, ^{1}H NMR, and ^{13}C NMR. In addition, second amine *N*-methylphenylamine and heteroaromatic tertiary amine 4-(dimethylamino)pyridine were also tested, but no reaction was detected (the data are not shown in Table 4). This may be because the second amine and electron-defect pyridine could not stabilize amine cation radical, which is generated in the photoredox process.

On the basis of our control experiments above and previous work,[9−13] we believe that the formation of tetrahydroquinolines involves the addition of α-aminoalkyl radicals to the double bond and subsequent free-radical cyclization as the key steps, and singlet oxygen was involved in the reaction mechanism. Thus, a plausible reaction pathway for this visible-light-induced cyclization reaction catalyzed by chlorophyll is proposed in

Table 3. Screening of Solvents and Catalyst Dosages[a]



1a **2a** **3a**

entry	chlorophyll (mg)	solvent	yield of **3a**[b] (%)
1	0.16	DMF	80
2	0.16	DMSO	76
3	0.16	MeCN	23
4	0.16	MeOH	23
5	0.16	THF	19
6	0.16	CH_2Cl_2	10
7	0.16	H_2O	trace
8	0.05	DMF	37
9	0.10	DMF	55
10	0.21	DMF	76

[a]Reaction conditions: a mixture of **1a** (0.50 mmol), **2a** (0.25 mmol), and 0.05–0.21 mg of chlorophyll (10–40 mg of chlorophyll powder preparation, in which total chlorophyll content is 0.52%) in a solvent (1.0 mL) was irradiated with a 23 W fluorescent lamp for 36 h. [b]Yield of the isolated product after silica gel chromatography.

Scheme 1. The absorption of a photon excites the chlorophyll from its ground state to its excited state (chlorophyll*). The excited state photosensitizer (chlorophyll*) transfers its energy to the ground-state oxygen, forming the singlet oxygen. Meanwhile, the excited state of the photosensitizer goes back to the ground state. A single-electron transfer (SET) from the tertiary amine **1** to the singlet oxygen leads to the amine cation radical **4**. At the same time, singlet oxygen accepts an electron to form superoxide anion radicals. Proton transfer from the amine cation radical **4** to the superoxide anion radical gives the α-aminoalkyl radical **5**. Radical addition of **5** to the maleimide **2** generates **6** and subsequent intramolecular cyclization leads to intermediate **7**. SET oxidation of **7** by oxygen forms a carbocation **8**, which was followed by deprotonation to furnish

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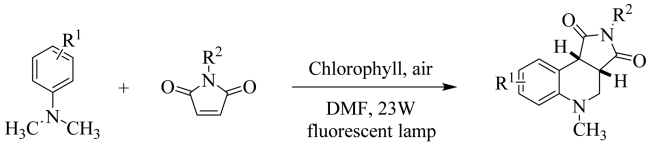
Table 4. Substrate Scope[a]

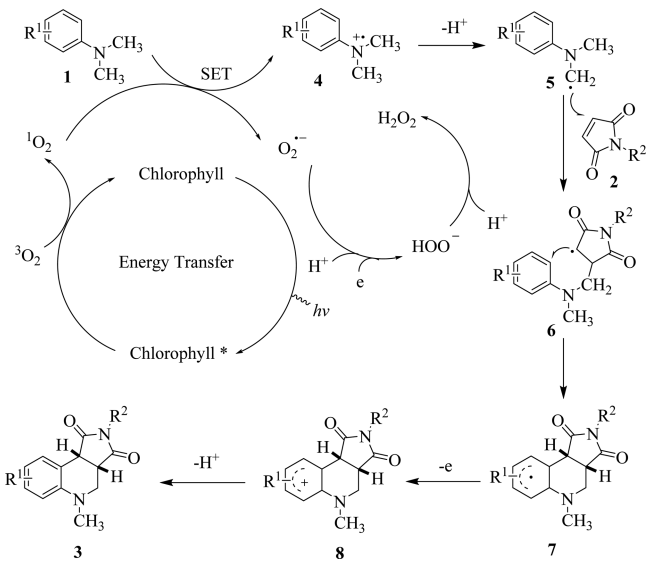


1 2 3

entry	R^1	R^2	product no.	time (h)	yield (%)[b]
1	4-Me	Ph	**3a**	36	89
2	4-Me	Me	**3b**	36	74
3	4-Me	Et	**3c**	36	72
4	4-Me	*t*-Bu	**3d**	48	62
5	4-Me	Bn	**3e**	36	83
6	H	Ph	**3f**	36	93
7	H	H	**3g**	30	97
8	H	Me	**3h**	36	93
9	H	Et	**3i**	36	87
10	H	*t*-Bu	**3j**	48	66
11	H	Bn	**3k**	36	95
12	4-F	Ph	**3l**	36	97
13	4-F	H	**3m**	30	98
14	4-F	Me	**3n**	36	89
15	4-F	Et	**3o**	36	84
16	4-F	Bn	**3p**	36	69
17	4-Cl	Ph	**3q**	36	98
18	4-Cl	H	**3r**	30	97
19	4-Cl	Me	**3s**	36	79
20	4-Cl	Et	**3t**	36	73
21	4-Cl	Bn	**3u**	36	80
22	4-Br	Ph	**3v**	36	96
23	4-Br	Me	**3w**	36	86
24	4-Br	Et	**3x**	36	90
25	4-Br	*t*-Bu	**3y**	48	61
26	4-Br	Bn	**3z**	36	75

[a]Reaction conditions: a mixture of **1** (0.50 mmol), **2** (0.25 mmol), and 0.16 mg of chlorophyll (30 mg of chlorophyll powder preparation, in which total chlorophyll content is 0.52%) in DMF (2.0 mL) was irradiated with a 23W fluorescent lamp. [b]Yield of the isolated product after silica gel chromatography.

Scheme 1. Proposed Reaction Mechanism



the desired product **3**. In this process, the protonation of superoxide radical anion would generate the HOO^- and then H_2O_2.

3. CONCLUSION

In conclusion, we have developed a green, facile, and efficient method for the synthesis of tetrahydroquinolines from *N*,*N*-dimethylanilines and maleimides. The protocol is significantly green because it utilizes visible light and atmospheric oxygen as the greenest reagents and natural pigment chlorophyll as the photosensitizer to deliver the product at room temperature in a simple procedure. This methodology provides a direct cyclization via an sp^3 C−H bond functionalization process to afford tetrahydroquionoline frameworks of importance in medicinal and pharmaceutical chemistry. Moderate to high yields (61−98%) were obtained from a wide range of substrates under mild conditions. This novel process provides an example for exploring an environmentally friendly, simple, and convenient synthetic route utilizing chlorophyll and light energy in organic chemistry.

4. EXPERIMENTAL SECTION

4.1. General Procedure for the Synthesis of Tetrahydroquinolines. A round-bottom flask was charged with 0.16 mg of chlorophyll (30 mg of chlorophyll powder preparation, in which total chlorophyll content is 0.52%), *N*,*N*-dimethylaniline **1** (0.50 mmol), maleimide **2** (0.25 mmol), and DMF (2.0 mL). The resultant mixture was stirred under irradiation of a 23 W fluorescent lamp (the parallel distance between the lamp and the reaction flask is 2 cm) at room temperature for the specified reaction time and monitored by TLC. The reaction mixture was filtered (with 40 mm Buchner funnel and qualitative filter paper) to remove lactose and gum arabic, which could not dissolve well in DMF. The ethyl acetate was employed to wash the residue on the filter paper to ensure that products obtained were all dissolved in the filtrate. The filtrate was washed with water three times, and then dried over anhydrous Na_2SO_4. The organic solvent was then removed under reduced pressure. The crude products were purified by silica gel column chromatography with petroleum ether/ethyl acetate as eluent (V_{PE}/V_{EA} = 2:1−12:1).

5,8-Dimethyl-2-phenyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]-quinoline-1,3(2H)-dione (***3a***) (*Table 4, Entry 1*).[7,9−11] White solid: yield 67.7 mg, 89%; mp 193−195 °C; R_f = 0.31 (petroleum ether/ethyl acetate 6:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.43−7.40 (m, 2H), 7.35−7.33 (m, 2H), 7.27−7.24 (m, 2H), 7.07 (d, *J* = 8.2 Hz, 1H), 6.68 (d, *J* = 8.2 Hz, 1H), 4.14 (d, *J* = 9.4 Hz, 1H), 3.61 (dd, *J* = 11.4, 2.5 Hz, 1H), 3.54 (ddd, *J* = 9.4, 4.4, 2.5 Hz, 1H), 3.09 (dd, *J* = 11.4, 4.4 Hz, 1H), 2.84 (s, 3H), 2.33 (s, 3H;. ^{13}C NMR (150 MHz, $CDCl_3$) δ = 177.7, 175.8, 146.4, 132.1, 130.8, 129.2, 129.0, 128.9, 128.5, 126.4, 118.5, 112.5, 51.0, 43.6, 42.2, 39.5, 20.4.

2,5,8-Trimethyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]quinoline-1,3(2H)-dione (***3b***) (*Table 4, Entry 2*).[7,10,11] White solid: yield 45.2 mg, 74%; mp 171−174 °C; R_f = 0.35 (petroleum ether/ethyl acetate 3:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.32 (s, 1H), 7.03 (d, *J* = 8.3 Hz, 1H), 6.63 (d, *J* = 8.3 Hz, 1H), 3.97 (d, *J* = 9.4 Hz, 1H), 3.53 (dd, *J* = 11.4, 2.3 Hz, 1H), 3.35 (ddd, *J* = 9.4, 4.5, 2.3 Hz, 1H), 3.01 (s, 3H), 2.95 (dd, *J* = 11.4, 4.5 Hz, 1H), 2.78 (s, 3H), 2.32 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 178.8, 176.8, 146.3, 130.7, 129.1, 128.9, 118.7, 112.5, 50.8, 43.6, 42.1, 39.5, 25.3, 20.4.

2-Ethyl-5,8-dimethyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]-quinoline-1,3(2H)-dione (***3c***) (*Table 4, Entry 3*). White solid: yield 46.5 mg, 72%; mp 117−119 °C; R_f = 0.36 (petroleum ether/ethyl acetate 3:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.32 (s, 1H), 7.03 (d, *J* = 8.2 Hz, 1H), 6.63 (d, *J* = 8.2 Hz, 1H), 3.94 (d, *J* = 9.4 Hz, 1H), 3.56 (m, 2H), 3.49 (dd, *J* = 11.4, 2.6 Hz, 1H), 3.33 (dd, *J* = 9.4, 4.6 Hz, 1H), 2.99 (dd, *J* = 11.4, 4.6 Hz, 1H), 2.78 (s, 3H), 2.32 (s, 3H), 1.16 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 178.8, 176.8, 146.3, 130.7, 129.1, 128.9, 118.7, 112.5, 50.8, 43.6, 42.1, 39.5, 25.3,

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20.4, 12.9; HRMS (ESI-TOF) calcd for $C_{15}H_{18}N_2O_2$ $(M + Na)^+$ 281.1260, found 281.1264.

*2-tert-Butyl-5,8-dimethyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]-quinoline-1,3(2H)-dione (**3d**) (Table 4, Entry 4).* Yellowish oil: yield 44.1 mg, 62%; R_f = 0.29 (petroleum ether/ethyl acetate 12:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.03 (d, J = 8.2 Hz, 1H), 6.63 (d, J = 8.2 Hz, 1H), 6.54 (s, 1H), 3.81 (d, J = 9.7 Hz, 1H), 3.42 (dd, J = 11.3, 3.3 Hz, 1H), 3.20 (ddd, J = 9.7, 4.6, 3.3 Hz, 1H), 2.96 (dd, J = 11.3, 4.6 Hz, 1H), 2.79 (s, 3H), 2.32 (s, 3H), 1.57 (s, 9H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 179.6, 177.9, 133.9, 130.8, 128.9, 119.2, 112.3, 58.7, 51.3, 43.2, 42.2, 39.5, 28.4, 20.4; HRMS (ESI-TOF) calcd for $C_{17}H_{22}N_2O_2$ $(M + Na)^+$ 309.1573, found 309.1582.

*2-Benzyl-5,8-dimethyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]-quinoline-1,3(2H)-dione (**3e**) (Table 4, Entry 5).*[7,9,11] White solid: yield 66.5 mg, 83%; mp 120−122 °C; R_f = 0.33 (petroleum ether/ethyl acetate 8:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.34−7.27 (m, 6H), 7.05 (d, J = 8.2 Hz, 1H), 6.65 (d, J = 8.2 Hz, 1H), 4.71 (d, J = 14.4 Hz, 1H), 4.64 (d, J = 14.4 Hz, 1H), 3.96 (d, J = 9.4 Hz, 1H), 3.50 (dd, J = 11.4, 2.5 Hz, 1H), 3.40 (ddd, J = 9.4, 4.5, 2.5 Hz, 1H), 3.01 (dd, J = 11.4, 4.5 Hz, 1H), 2.80 (s, 3H), 2.33 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 178.4, 176.5, 146.3, 135.7, 130.8, 129.1, 129.0, 128.6, 128.3, 127.8, 118.9, 112.4, 51.1, 43.7, 42.8, 42.2, 39.4, 20.4.

*5-Methyl-2-phenyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]-quinoline-1,3(2H)-dione (**3f**) (Table 4, Entry 6).*[7,9−12] White solid: yield 67.9 mg, 93%; mp 203−205 °C; R_f = 0.27 (petroleum ether/ethyl acetate 6:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.57−7.31(m, 4H), 7.30−7.27 (m, 3H), 6.95 (d, J = 8.2 Hz, 1H), 6.78 (d, J = 8.2 Hz, 1H), 4.17 (d, J = 9.6 Hz, 1H), 3.63 (dd, J = 11.5, 2.6 Hz, 1H), 3.56 (ddd, J = 9.6, 4.4, 2.6 Hz, 1H), 3.14 (dd, J = 11.5, 4.4 Hz, 1H), 2.87 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 177.6, 175.7, 148.5, 132.1, 130.4, 129.0, 128.7, 128.5, 126.4, 119.7, 118.6, 112.5, 50.7, 43.6, 42.2, 39.4.

*5-Methyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]quinoline-1,3(2H)-dione (**3g**) (Table 4, Entry 7).* White solid: yield 52.6 mg, 97%; mp 77−79 °C; R_f = 0.18 (petroleum ether/ethyl acetate 2:1); ^{1}H NMR (600 MHz, DMSO-d_6) δ = 11.30 (br, 1H), 7.30 (d, J = 7.4 Hz, 1H), 7.17−7.15 (m, 1H), 6.83−6.81 (m, 1H), 6.73 (d, J = 7.4 Hz, 1H), 4.01 (d, J = 9.4 Hz, 1H), 3.45 (ddd, J = 9.4, 4.7, 2.3 Hz, 1H), 3.33 (dd, J = 11.5, 2.3 Hz, 1H), 2.87 (dd, J = 11.5, 4.7 Hz, 1H), 2.72 (s, 3H); ^{13}C NMR (150 MHz, DMSO-d_6) δ = 180.6, 178.6, 148.9, 130.4, 128.3, 120.1, 119.2, 112.7, 50.8, 44.4, 43.3, 39.7; HRMS (ESI-TOF) calcd for $C_{12}H_{12}N_2O_2$ $(M + H)^+$ 217.0972, found 217.0976.

*2,5-Dimethyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]quinoline-1,3(2H)-dione (**3h**) (Table 4, Entry 8).*[10,11] White solid: yield 53.3 mg, 93%; mp 171−173 °C; R_f = 0.24 (petroleum ether/ethyl acetate 3:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.50 (d, J = 7.5 Hz, 1H), 7.24−7.21 (m, 1H), 6.91 (m, 1H), 6.72 (d, J = 7.5 Hz, 1H), 4.01 (d, J = 9.4 Hz, 1H), 3.55 (dd, J = 11.5, 2.4 Hz, 1H), 3.38 (ddd, J = 9.4, 4.5, 2.4 Hz, 1H), 3.06 (dd, J = 11.5, 4.5 Hz, 1H), 3.00 (s, 3H), 2.82 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 178.7, 176.8, 148.4, 130.2, 128.6, 119.6, 118.7, 112.5, 50.5, 43.6, 42.0, 39.4, 25.3.

*2-Ethyl-5-methyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]-quinoline-1,3(2H)-dione (**3i**) (Table 4, Entry 9).* Yellowish oil: yield 53.3 mg, 87%; R_f = 0.32 (petroleum ether/ethyl acetate 3:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.50 (d, J = 7.5 Hz, 1H), 7.24−7.21 (m, 1H), 6.91 (m, 1H), 6.72 (d, J = 7.5 Hz, 1H), 3.98 (d, J = 9.4 Hz, 1H), 3.62−3.53 (m, 2H), 3.52 (d, J = 9.4 Hz, 1H), 3.37−3.35 (m, 1H), 3.07−3.04 (m, 1H), 2.82 (s, 3H), 1.16 (t, J = 7.2 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 178.4, 176.5, 148.4, 130.2, 128.5, 119.6, 118.9, 112.4, 50.7, 43.5, 42.0, 39.4, 34.2, 12.9; HRMS (ESI-TOF) calcd for $C_{14}H_{16}N_2O_2$ $(M + Na)^+$ 267.1104, found 267.1107.

*2-tert-Butyl-5-methyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]-quinoline-1,3(2H)-dione (**3j**) (Table 4, Entry 10).*[11] White solid: yield 44.8 mg, 66%; mp 77−79 °C; R_f = 0.29 (petroleum ether/ethyl acetate 12:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.47 (d, J = 7.5 Hz, 1H), 7.23 (m, 1H), 6.90 (m, 1H), 6.73 (d, J = 7.5 Hz, 1H), 3.85 (d, J = 9.7 Hz, 1H), 3.45 (dd, J = 11.4, 2.9 Hz, 1H), 3.23 (ddd, J = 9.7, 4.5, 2.9 Hz,1H), 3.03 (dd, J = 11.4, 4.5 Hz, 1H), 2.83 (s, 3H), 1.57 (s, 9H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 179.5, 177.8, 148.3, 130.3, 128.4, 119.3, 119.2, 112.3, 58.7, 50.9, 43.2, 42.1, 39.3, 28.4.

*2-Benzyl-5-methyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]-quinoline-1,3(2H)-dione (**3k**) (Table 4, Entry 11).*[11,12] White solid: yield 72.5 mg, 95%; mp 126−128 °C; R_f = 0.30 (petroleum ether/ethyl acetate 8:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.50 (d, J = 7.5 Hz, 1H), 7.34−7.23 (m, 6H), 6.93 (m, 1H), 6.74 (d, J = 7.5 Hz, 1H), 4.71 (d, J = 14.4 Hz, 1H), 4.65 (d, J = 14.4 Hz, 1H), 4.00 (d, J = 9.4 Hz, 1H), 3.52 (dd, J = 11.5, 2.6 Hz, 1H), 3.37 (ddd, J = 9.4, 4.5, 2.6 Hz, 1H), 3.07 (dd, J = 11.5, 4.5 Hz, 1H), 2.83 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 178.3, 176.4, 148.5, 135.6, 130.3, 128.6, 128.5, 128.3, 127.8, 119.7, 118.9, 112.4, 50.8, 43.7, 42.8, 42.1, 39.3.

*8-Fluoro-5-methyl-2-phenyl-3a,4,5,9b-tetrahydro-1H-pyrrolo-[3,4-c]quinoline-1,3(2H)-dione (**3l**) (Table 4, Entry 12).*[9,11] White solid: yield 75.4 mg, 97%; mp 171−173 °C; R_f = 0.31 (petroleum ether/ethyl acetate 9:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.41−7.38 (m, 2H), 7.33−7.31 (m, 1H), 7.22−7.21 (m, 3H), 6.90−6.88 (m, 1H), 6.64−6.62 (m, 1H), 4.09 (d, J = 9.4 Hz, 1H), 3.54 (dd, J = 11.4, 2.6 Hz, 1H), 3.50 (ddd, J = 9.4, 3.9, 2.6 Hz, 1H), 3.03 (dd, J = 11.4, 3.9 Hz, 1H), 2.77 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 177.4, 175.2, 156.5 (d, $^1J_{C-F}$ = 237.0 Hz), 145.0 (d, J = 1.7 Hz), 131.9, 129.0, 128.5, 126.3, 120.1 (d, J = 7.6 Hz), 116.9 (d, J = 23.2 Hz), 114.9 (d, J = 21.9 Hz), 113.3 (d, J = 7.6 Hz), 51.0, 43.4, 42.2, 39.7.

*8-Fluoro-5-methyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]-quinoline-1,3(2H)-dione (**3m**) (Table 4, Entry 13).* Yellowish oil: yield 57.5 mg, 98%; R_f = 0.25 (petroleum ether/ethyl acetate 2:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 8.57 (br, 1H), 7.21−7.20 (m, 1H), 6.94−6.83 (m, 1H), 6.68−6.66 (m, 1H), 4.01 (d, J = 9.5 Hz, 1H), 3.50 (dd, J = 11.5, 2.6 Hz, 1H), 3.43 (ddd, J = 9.5, 4.3, 2.6 Hz, 1H), 3.01 (dd, J = 11.5, 4.3 Hz, 1H), 2.81 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 178.3, 175.9, 156.6 (d, $^1J_{C-F}$ = 237.4 Hz), 144.9 (d, J = 2.0 Hz), 119.9(d, J = 7.4 Hz), 116.7(d, J = 23.2 Hz), 115.0(d, J = 21.9 Hz), 113.4 (d, J = 7.6 Hz), 50.8, 44.6, 43.3, 39.7; HRMS (ESI-TOF) calcd for $C_{12}H_{11}FN_2O_2$ $(M + H)^+$ 235.0877, found 235.0884.

*8-Fluoro-2,5-dimethyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]-quinoline-1,3(2H)-dione (**3n**) (Table 4, Entry 14).* White solid: yield 55.4 mg, 89%; mp 136−138 °C; R_f = 0.23 (petroleum ether/ethyl acetate 3:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.24−7.22 (m, 1H), 6.93−6.90 (m, 1H), 6.64−6.62 (m, 1H), 3.97 (d, J = 9.4 Hz, 1H), 3.51 (dd, J = 11.5, 2.5 Hz, 1H), 3.37 (ddd, J = 9.4, 4.5, 2.5 Hz, 1H), 3.01 (s, 3H), 2.99 (d, J = 4.5 Hz, 1H), 2.78 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 178.4, 176.1, 157.4, 155.8 (d, $^1J_{C-F}$ = 237.1 Hz), 144.8 (d, J = 1.9 Hz), 120.1 (d, J = 7.5 Hz), 116.8(d, J = 23.1 Hz), 114.8(d, J = 21.2 Hz), 113.3 (d, J = 7.5 Hz), 50.9, 43.4, 42.1, 39.7, 25.4; HRMS (ESI-TOF) calcd for $C_{13}H_{13}FN_2O_2$ $(M + H)^+$ 249.1034, found 249.1036.

*2-Ethyl-8-fluoro-5-methyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]quinoline-1,3(2H)-dione (**3o**) (Table 4, Entry 15).* White solid: yield 55.0 mg, 84%; mp 122−124 °C; R_f = 0.30 (petroleum ether/ethyl acetate 3:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.25−7.23 (m, 1H), 6.94−6.90 (m, 1H), 6.65−6.63 (m, 1H), 3.94 (d, J = 9.4 Hz, 1H), 3.56 (m, 2H), 3.49 (dd, J = 11.5, 2.7 Hz, 1H), 3.35 (ddd, J = 9.4, 4.6, 2.7 Hz, 1H), 3.01 (dd, J = 11.5, 4.6 Hz, 1H), 2.79 (s, 3H), 1.16 (t, J = 7.2 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 178.1, 175.9, 156.6 (d, $^1J_{C-F}$ = 237.1 Hz), 144.9 (d, J = 1.7 Hz), 120.3 (d, J = 7.6 Hz), 116.8 (d, J = 23.1 Hz), 114.8 (d, J = 21.8 Hz), 113.2 (d, J = 7.6 Hz), 51.0, 43.3, 42.1, 39.7, 34.3, 12.9; HRMS (ESI-TOF) calcd for $C_{14}H_{15}FN_2O_2$ $(M + H)^+$ 263.1190, found 263.1193.

*2-Benzyl-8-fluoro-5-methyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]quinoline-1,3(2H)-dione (**3p**) (Table 4, Entry 16).* White solid: yield 56.1 mg, 69%; mp 123−125 °C; R_f = 0.33 (petroleum ether/ethyl acetate 10:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.36−7.26 (m, 5H), 7.24−7.21 m, 1H), 6.94−6.92 (m, 1H), 6.66−6.64 (m, 1H), 4.71 (d, J = 14.4 Hz, 1H), 4.65 (d, J = 14.4 Hz, 1H), 3.96 (d, J = 9.4 Hz, 1H), 3.49 (dd, J = 11.5, 2.7 Hz, 1H), 3.37 (ddd, J = 9.4, 4.6, 2.7 Hz, 1H), 3.02 (dd, J = 11.5, 4.6 Hz, 1H), 2.79 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 178.0, 175.8, 156.6, (d, $^1J_{C-F}$ = 237.2 Hz), 144.9 (d, J = 1.8 Hz), 135.5, 128.6, 128.3, 127.8, 120.3 (d, J = 7.6 Hz), 116.9 (d, J = 23.1 Hz), 114.9(d, J = 21.8 Hz), 113.2 (d, J = 7.6 Hz), 51.1, 43.5, 42.9, 42.2, 39.6; HRMS (ESI-TOF) calcd for $C_{19}H_{17}FN_2O_2$ $(M + Na)^+$ 347.1166, found 347.1170.

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*8-Chloro-5-methyl-2-phenyl-3a,4,5,9b-tetrahydro-1H-pyrrolo-[3,4-c]quinoline-1,3(2H)-dione (**3q**) (Table 4, Entry 17).*[9,11] White solid: yield 79.9 mg, 98%; mp 157−159 °C; R_f = 0.29 (petroleum ether/ethyl acetate 3:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.48−7.24 (m, 6H), 7.15 (d, J = 8.8 Hz, 1H), 6.64 (d, J = 8.8 Hz, 1H), 4.08 (d, J = 9.6 Hz, 1H), 3.58 (dd, J = 11.5, 2.7 Hz, 1H), 3.52 (ddd, J = 9.6, 4.4, 2.7 Hz, 1H), 3.08 (dd, J = 11.6, 4.4 Hz, 1H), 2.81 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 177.2, 175.1, 147.1, 131.9, 129.9, 129.0, 128.6, 128.5, 126.3, 124.4, 120.0, 113.7, 50.5, 43.3, 41.9, 39.4.

*8-Chloro-5-methyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]-quinoline-1,3(2H)-dione (**3r**) (Table 4, Entry 18).* White solid: yield 60.9 mg, 97%; mp 177−179 °C; R_f = 0.25 (petroleum ether/ethyl acetate 2:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 9.56 (br, 1H), 7.40 (d, J = 2.2 Hz, 1H), 7.14 (dd, J = 8.7, 2.2 Hz, 1H), 6.62 (d, J = 8.7 Hz, 1H), 3.95 (d, J = 9.5 Hz, 1H), 3.47 (dd, J = 11.6, 2.7 Hz, 1H), 3.39 (ddd, J = 9.5, 4.5, 2.7 Hz, 1H), 2.99 (dd, J = 11.6, 4.5 Hz, 1H), 2.79 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 178.8, 176.5, 147.0, 129.7, 128.3, 124.3, 120.1, 113.6, 50.3, 44.4, 43.0, 39.4; HRMS (ESI-TOF) calcd for $C_{12}H_{10}ClN_2O_2$ $(M - H)^-$ 249.0425, found 249.0428.

*8-Chloro-2,5-dimethyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]-quinoline-1,3(2H)-dione (**3s**) (Table 4, Entry 19).*[16] White solid: yield 52.5 mg, 79%; mp 174−177 °C; R_f = 0.30 (petroleum ether/ethyl acetate 3:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.46 (d, J = 2.1 Hz, 1H), 7.15 (dd, J = 8.7, 2.1 Hz, 1H), 6.62 (d, J = 8.7 Hz, 1H), 3.95 (d, J = 9.4 Hz, 1H), 3.53 (dd, J = 11.6, 2.5 Hz, 1H), 3.37 (ddd, J = 9.4, 4.5, 2.5 Hz, 1H), 3.03 (dd, J = 11.6, 4.5 Hz, 1H), 3.00 (s, 3H), 2.79 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 178.2, 176.1, 147.0, 129.8, 128.4, 124.4, 120.2, 113.7, 50.4, 43.3, 41.8, 39.4, 25.4.

*8-Chloro-2-ethyl-5-methyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]quinoline-1,3(2H)-dione (**3t**) (Table 4, Entry 20).* White solid: yield 51.1 mg, 73%; mp 121−123 °C; R_f = 0.29 (petroleum ether/ethyl acetate 4:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.47 (d, J = 2.3 Hz, 1H), 7.16 (dd, J = 8.7, 2.3 Hz, 1H), 6.63 (d, J = 8.7 Hz, 1H), 3.93 (d, J = 9.4 Hz, 1H), 3.57−3.56 (m, 2H), 3.50 (dd, J = 11.5, 2.8 Hz, 1H), 3.35 (ddd, J = 9.4, 4.6, 2.8 Hz, 1H), 3.04 (dd, J = 11.5, 4.6 Hz, 1H), 2.80 (s, 3H), 1.16 (t, J = 7.2 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 177.9, 175.8, 147.0, 129.8, 128.3, 124.4, 120.3, 113.6, 50.5, 43.2, 41.7, 39.4, 34.4, 12.9; HRMS (ESI-TOF) calcd for $C_{14}H_{15}ClN_2O_2$ $(M + H)^+$: 279.0895, found 279.0901.

*2-Benzyl-8-chloro-5-methyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]quinoline-1,3(2H)-dione (**3u**) (Table 4, Entry 21).* White solid: yield 68.2 mg, 80%; mp 141−143 °C; R_f = 0.34 (petroleum ether/ethyl acetate 3:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.47 (d, J = 2.0 Hz, 1H), 7.35−7.24 (m, 5H), 7.17 (dd, J = 8.7, 2.0 Hz, 1H), 6.64 (d, J = 8.7 Hz, 1H), 4.70 (d, J = 14.3 Hz, 1H), 4.64 (d, J = 14.3 Hz, 1H), 3.93 (d, J = 9.4 Hz, 1H), 3.49 (dd, J = 11.5, 2.7 Hz, 1H), 3.36 (ddd, J = 9.4, 4.6, 2.7 Hz, 1H), 3.05 (dd, J = 11.5, 4.6 Hz, 1H), 2.80 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 177.9, 175.7, 147.1, 135.5, 129.9, 128.6, 128.4, 128.3, 127.9, 124.5, 120.3, 113.6, 50.7, 43.4, 42.9, 41.9, 39.4; HRMS (ESI-TOF) calcd for $C_{19}H_{17}ClN_2O_2$ $(M + Na)^+$: 363.0871, found 363.0876.

*8-Bromo-5-methyl-2-phenyl-3a,4,5,9b-tetrahydro-1H-pyrrolo-[3,4-c]quinoline-1,3(2H)-dione (**3v**) (Table 4, Entry 22).*[9,11,12] White solid: yield 89.0 mg, 96%; mp 157−159 °C; R_f = 0.28 (petroleum ether/ethyl acetate 3:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.66−7.65 (m, 1H), 7.46−7.44 (m, 2H), 7.41−7.37 (m, 1H), 7.36−7.32 (m, 1H), 7.32−7.25 (m, 2H), 6.63−6.61 (m, 1H), 4.09 (d, J = 9.5 Hz, 1H), 3.61 (ddd, J = 11.3, 4.9, 2.8 Hz, 1H), 3.53 (dd, J = 9.5, 2.8 Hz 1H), 3.11 (dd, J = 11.3, 4.9 Hz, 1H), 2.83 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 177.2, 175.1, 147.5, 132.7, 132.0, 131.4, 129.0, 128.6, 126.3, 120.5, 114.2, 111.6, 50.4, 43.3, 41.8, 39.4.

*8-Bromo-2,5-dimethyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]-quinoline-1,3(2H)-dione (**3w**) (Table 4, Entry 23).*[10,11] White solid: yield 66.1 mg, 86%; mp 187−189 °C; R_f = 0.26 (petroleum ether/ethyl acetate 3:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.60 (s, 1H), 7.28 (d, J = 8.7 Hz, 1H), 6.57 (d, J = 8.7 Hz, 1H), 3.95 (d, J = 9.4 Hz, 1H), 3.53 (dd, J = 11.6, 2.2 Hz, 1H), 3.37 (ddd, J = 9.4, 4.5, 2.2 Hz, 1H), 3.04 (dd, J = 11.6, 4.5 Hz, 1H), 3.00 (s, 3H), 2.79 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 178.2, 176.1, 147.4, 132.6, 131.3, 120.6, 114.1, 111.6, 50.3, 43.3, 41.7, 39.4, 25.4.

*8-Bromo-2-ethyl-5-methyl-3a,4,5,9b-tetrahydro-1H-pyrrolo[3,4-c]quinoline-1,3(2H)-dione (**3x**) (Table 4, Entry 24).* White solid: yield 72.8 mg, 90%; mp 128−130 °C; R_f = 0.31 (petroleum ether/ethyl acetate 3:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.58−7.57 (m, 1H), 7.28−7.27 (m, 1H), 6.57−6.56 (m, 1H), 3.91 (d, J = 9.4 Hz, 1H), 3.59−3.51 (m, 2H), 3.48 (dd, J = 11.6, 2.7 Hz, 1H), 3.34 (ddd, J = 9.4, 4.6, 2.7 Hz, 1H), 3.03 (dd, J = 11.6, 4.6 Hz, 1H), 2.78 (s, 3H), 1.14 (t, J = 7.2 Hz, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 177.9, 175.8, 147.4, 132.6, 131.2, 120.8, 114.1, 111.5, 50.4, 43.2, 41.6, 39.4, 34.3, 12.9; HRMS (ESI-TOF) calcd for $C_{14}H_{15}BrN_2O_2$ $(M + Na)^+$ 345.0209, found 345.0211.

*8-Bromo-2-tert-butyl-5-methyl-3a,4,5,9b-tetrahydro-1H-pyrrolo-[3,4-c]quinoline-1,3(2H)-dione (**3y**) (Table 4, Entry 25).* White solid: yield 53.8 mg, 61%; mp 115−117 °C; R_f = 0.29 (petroleum ether/ethyl acetate 10:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.57−7.56 (m, 1H), 7.29−7.28 (m, 1H), 6.59−6.57 (m, 1H), 3.79 (d, J = 9.7 Hz, 1H), 3.43 (dd, J = 11.5, 3.1 Hz, 1H), 3.22 (ddd, J = 9.7, 4.6, 3.1 Hz, 1H), 3.01 (dd, J = 11.5, 4.6 Hz, 1H), 2.80 (s, 3H), 1.56 (s, 9H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 179.0, 177.0, 147.3, 132.7, 131.1, 121.1, 114.0, 111.3, 58.9, 50.6, 42.8, 41.8, 39.4, 28.3; HRMS (ESI-TOF) calcd for $C_{16}H_{19}BrN_2O_2$ $(M + Na)^+$ 373.0522, found 373.0525.

*2-Benzyl-8-bromo-5-methyl-3a,4,5,9b-tetrahydro-1H-pyrrolo-[3,4-c]quinoline-1,3(2H)-dione (**3z**) (Table 4, Entry 26).*[11] White solid: yield 72.5 mg, 75%; mp 148−150 °C; R_f = 0.23 (petroleum ether/ethyl acetate 3:1); ^{1}H NMR (600 MHz, $CDCl_3$) δ = 7.60−7.59 (m, 1H), 7.35−7.25 (m, 6H), 6.59−6.58 (m, 1H), 4.70 (d, J = 14.3 Hz, 1H), 4.64 (d, J = 14.3 Hz, 1H), 3.93 (d, J = 9.4 Hz, 1H), 3.49 (dd, J = 11.5, 2.8 Hz, 1H), 3.37 (ddd, J = 9.4, 4.6, 2.8 Hz, 1H), 3.05 (dd, J = 11.5, 4.6 Hz, 1H), 2.80 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ = 177.8, 175.7, 147.5, 135.5, 132.7, 131.3, 128.6, 128.3, 127.9, 120.7, 114.1, 111.7, 50.6, 43.4, 42.9, 41.7, 39.3.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.6b03034.

Materials, analytical methods, extra information for optimization of reaction conditions, UV−vis absorption of chlorophyll, gum arabic, and lactose, and ^{1}H NMR, ^{13}C NMR, and HRMS spectra (PDF)

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Notes

The authors declare no competing financial interest.

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