Synthesis of 3,4-dioxocularine and aristocularine alkaloids in a convergent route from aryloxy-phenyl acetamides involving oxalyl chloride-Lewis Acid

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Dedicated to Professor Marcial Moreno-Mañas on the occasion of his 60th birthday
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Abstract
Double cyclization of aryloxy-phenyl acetamides is promoted by oxalyl chloride/stannyl chloride and gives 3,4-dioxocularine and aristocularine alkaloids. Rearrangement of the dibenzoxepine ring prior to the second cyclization produces xanthene derivatives. The synthesized cularinoids exhibit significant activity against various tumoral cell lines.

Keywords: Aryloxyphenyl acetamides, 3,4-dioxocularine, aristocularine, alkaloids, double cyclization

Introduction
Cularinoids are a group of isoquinoline alkaloids consisting of about sixty members that are characterized by the dibenzoxepine skeleton and occur naturally in various oxidation states. Among them, 3,4-dioxocularines and aristocularines are oxidized cularinoids characterized by the tetracyclic structure 1 and 2, respectively.1 Partial synthesis of 3,4-dioxocularines has been accomplished by chemical oxidation of 4-hydroxycularines with DDQ.2a-c Aristocularines are prepared by benzylic type rearrangement of 3,4-dioxocularines and decarbonylation in an alkaline medium.2b Aristoyagonine 2 was the first five-membered lactam derivative isolated from natural sources.2e A partial synthesis for this alkaloid involving a multistep sequence from 4-hydroxsarcocapnine has been reported.2b Its total synthesis has been achieved by annelation of metallated bromo-dibenzoepine (Scheme 1).2c
A few years ago, we developed new approaches to the synthesis of 4,5-dioxoaporphines from preformed biaryl bond precursors. We found biarylacetamides to undergo a cascade reaction including a double cyclization induced by oxalyl chloride/Lewis acid. Extension of this double cyclization to phenylethyl phenylacetamides provided a much simpler way to access C-homoberbines and protoberberine alkaloids.

Based on this approach, in this work we examined the reaction of aryloxy-phenyl acetamides with oxalyl chloride-Lewis acid to promote a double cyclization with a view to obtaining various 3,4-dioxocularines and aristocularines.

**Results and Discussion**

The reactivity of oxalyl chloride with amides has been studied by Speziale. Oxalyl chloride is known to react with secondary amides to give the 2-chloro-oxazolidine-4,5-dione ring. The addition of Lewis acids to these halogenated heterocycles derived from phenethylamides yields N-acyliminium ions; these act as superior acylating agents in the synthesis of isoquinolines.

We designed the synthesis of 3,4-dioxocularines in two stages. First, Ullmann condensation would allow easy access to the aryloxy-phenyl acetamides, as starting products, and then, activation of these amides with oxalyl chloride/Lewis acid would induce double cyclization and the sequential formation of rings C and B in the cularine skeleton. The presence of two oxygenated substituents at ring A in the starting acetamide ensures appropriate activation of the aromatic system, which must compensate for the formation of the seven-member dibenzoepine ring in the first cyclization.

Starting products were prepared by classical Ullmann condensation of guaiacol with the bromo-phenylacetates. Efficient aminolysis of the ester group gave the aryloxy-phenyl acetamides (Scheme 2). Compound was also prepared in good yield by direct Ullmann condensation of guaiacol and 2-bromo-3,4-methylenedioxy-phenyl N-methylacetamide.
The reaction of the amide 6a, b with oxalyl chloride and stannyl chloride was carried out at 70 °C (Scheme 3). Under these conditions, three reaction products were obtained that were characterized from their spectroscopic properties as the 3,4-dioxocularines 7a, b, the aristocularines 8a, b, and the chloro-xanthene derivatives 9a, b. The structures of dioxocularine 7a and aristocularine 8a were also identified by comparison with authentic samples.  

Further proof of the structure of 9b was obtained chemically. Thus, treatment of the isomeric mixture of both Z/E 9b with magnesium in THF, followed by careful addition of humid THF, led to the reduction of the vinyl chloride to afford 10b as a single product (Scheme 4). This methylene derivative was oxidized by air to the corresponding xanthone 11b.

The mechanism of the reaction involves (Scheme 5) firstly the 2-chloro-oxazolidine-4,5-dione I, formed by reaction of the amide with oxalyl chloride. This intermediate, I, is in equilibrium with the 2-methylene-oxazolidine-4,5-dione II, as found by 1H-NMR. In fact, when a dichloromethane solution of compound 6a was treated with excess oxalyl chloride for 10 min
at room temperature, and the solvent and excess reagent were removed under vacuum, the alkylidene derivative II was obtained in virtually quantitative yield (see experimental part). When stannyl chloride was added over I⇔II, the N-acyliminium ion must be formed, and the electrophilic substitution led to the spiro-oxazolidinedione intermediate III. Opening of the spiro intermediate III (path a) in a, probably, HCl-catalyzed reaction, would give the dibenzoepine-oxalylamide derivative (IV, X = OH), which should react with excess oxalyl chloride to give the corresponding acid chloride (IV, X = Cl). A Friedel-Craft reaction catalyzed by stannyl chloride accounts for the formation of the dioxocularine 7a.

![Scheme 5. Cyclization of amides with oxalyl chloride and stannyl chloride.](image)

Initially, we suspected that the formation of the aristocularine 8a was due to ring B decarbonylation of dioxocularine 7a. However, when dioxocularine 7a was subjected to the reaction conditions [(COCl)₂/SnCl⁴/70 °C] for 5 h, no decarbonylation product such as 8a was detected. Therefore, we assume that the formation of aristocularine 8a should be due to decarbonylation of the oxalylamide intermediate IV to the monocarbonyl derivative V, with final acylation to the aristocularine 8a. The formation of phosgene in the mixture of oxalyl chloride with Lewis acids is not without precedent.

We hypothesize that xanthene derivative 9a is formed by ring-C contraction of the dibenzoepine from the common intermediate III (path b) leading to the cyclopropane intermediate VI. The attack of chloride ion on the cyclopropane intermediate and elimination of the oxalylamide residue from intermediate VII should generate the exocyclic double bond of 9a. This rearrangement has been observed in dibenzoepinones in acidic media, and has been investigated in order to use this reaction as the key step in the synthesis of clavizepine (Scheme 5).
The reaction of 6c with oxalyl chloride and stannyl chloride was carried out under similar conditions to those described previously (Scheme 6). The reaction was showed to introduce significant differences. From silica gel column chromatography of the reaction mixture, the expected 3,4-dioxocularine 7c and aristocularine 8c were isolated, together with the unexpected dihydroaristocularine 12c.

Compound 12c exhibits the characteristic 1H-NMR spectrum for reduced cularine alkaloids, with an ABX system at 4.50 ppm (dd, $J = 11.3, 2.7$ Hz), 3.41 ppm (dd, $J = 13.6$ and $2.7$ Hz) and 2.87 ppm (bt) corresponding to the protons at positions 1 and $\alpha$. The formation of this product might be related to the non-oxidative decarbonylation of the oxalylamide intermediate IV (Scheme 5). What we know, so far, is that the proton at position 1 comes from the quenching of the reaction with water. In fact, when the reaction mixture was treated with D$_2$O, product 12cD was isolated with position 1 quantitatively deuterated.

Scheme 6. Reaction of the amide 6c.

When the reaction of amide 6a was carried out at a lower temperature (5 °C), a higher percentage of xanthene derivative 9a was obtained together with unreacted amide. Changing the solvent from methylene chloride to carbon disulfide decreased the reaction rate and the yield of cyclization products. With other Lewis acids such as BF$_3$·OEt$_2$, titanium tetrachloride, iron trichloride or aluminum chloride, no cyclization products were obtained as inferred from the 1H-NMR spectrum for the reaction crude.

The cytotoxicity of cularinoids was also analyzed. The results are shown in Table 1. The potency of these cularinoids as cytotoxic agents varied among cell lines. The compounds exhibited significant activity against both wild-type and adriamycin-resistant P-388 cell lines, and were also active against H-29 human colon adenocarcinoma and MDA-MB-231 human breast carcinoma cells. The IC$_{50}$ values obtained are consistent with those reported for aporphine alkaloids and suggest that cularinoids may function as antineoplastic agents.

Table 1. Cytotoxicity data, IC$_{50}$ (µg/mL), treatment for 48 h

| Compound         | Cell Line |
|------------------|-----------|
|                  | MDA       | HT-29     | P-388     | SCHABEL   |
| **3,4-Dioxocularines** |           |           |           |           |
| 7a, Dioxocularine| 3.7       | 8.5       | 1.0       | 2.3       |
| 7b                | 5.0       | 6.0       | 2.6       | 3.0       |
| 7c                | 7.3       | 5.9       | 2.6       | 3.0       |
| **Aristocularines** |           |           |           |           |
| 8a, Aristocularine| 2.9       | 7.5       | <0.8      | <0.9      |
In conclusion, a new, short synthesis of oxidized cularinoids based on the cyclization of aryloxy-phenyl acetamides to build up the rings B and C in a cascade reaction promoted by oxalyl chloride and stannyl chloride was developed. The reaction exhibits major differences with those reported for the formation of 4,5-dioxoaporphines, where no aristolactams are formed and, consequently, yields for dioxoaporphines are much higher. Probably, the second cyclization and ring B formation are facilitated in aporphine by the rigidity of the phenanthrene structure. The flexibility of the dibenzoepine skeleton may hinder cyclization, thus favoring the competitive decarbonylation process.

Experimental Section

General Procedures. Melting points (uncorrected) were determined on a Gallenkamp instrument. UV-spectra were recorded on a Hewlett-Packard 8452A spectrophotometer and IR-spectra on a Perkin-Elmer 883 spectrophotometer. Low- and high-resolution mass spectra were recorded on a HP-MS 5988A and a Kratos MS 50 spectrometer, respectively, both operating at 70 eV. 1H- and 13C-NMR spectra were obtained on Bruker WP-200 SY instrument, at 200 MHz for 1H and 50.3 MHz for 13C. 1H Chemical shifts are given relative to residual CHCl3 (δH 7.24 ppm) in deuteriochloroform. Coupling constants, J, value are given in Hz. 13C Chemical shifts are given relative to CDCl3 (δC 77.0 ppm) in deuteriochloroform. Analytical TLC was performed on silica gel 60 F254 (Merck) plates and visualized by UV light. Column chromatography (cc) was carried out on silica gel 60 (70-230 mesh).

Ullmann condensation of the methyl esters 4a-c. Synthesis of esters 5a-c. General procedure

A mixture of 4a-c (20 mmol), guaiacol 3 (5.0 g, 40 mmol), copper (0.6 g), copper oxide (4 g), potassium carbonate (5.6 g) and pyridine (30 mL) was refluxed for 36 h under an Ar atmosphere. The cooled reaction mixture was filtered over celite and thoroughly washed with dichloromethane. The filtrates were washed with 1 M hydrochloric acid, 1 M sodium hydroxide and water, dried over anhydrous MgSO4 and concentrated to give the title compounds 5a-c.

Methyl 2-(2'-methoxyphenoxy)-4,5-dimethoxy-phenylacetate (5a). Colorless syrup, 4.98 g, 75%; 1H-NMR δ (CDCl3) 7.04-6.64 (5H, m, Ar-H), 6.46 (1H, s, Ar-H), 3.88 (3H, s, OMe), 3.86 (3H, s, OMe), 3.72 (3H, s, OMe), 3.60 (2H, s, CH2), 3.57 (3H, s, OMe); 13C-NMR δ (CDCl3) 172.0 (CO), 149.9, 148.9, 147.8, 147.1, 145.4 (C), 117.2 (C-1), 123.1, 120.8, 117.4, 113.4, 112.4, 104.1 (CH), 56.2, 56.0, 56.0, 51.9 (4xOMe), 34.8 (CH2); m/z (%) 332 (M+), 100, 317
Methyl 2-(2'-methoxyphenoxy)-4,5-methylenedioxy-phenylacetate (5b). White solid, 4.55 g, 72%; mp 79-81 °C; $^1$H-NMR δ (CDCl$_3$) 7.1-6.7 (4H, m, Ar-H), 6.74 (1H, s, Ar-H), 6.36 (1H, s, Ar-H), 5.89 (2H, s, OCH$_2$O), 3.84 (3H, s, OMe), 3.61 (2H, s, CH$_2$), 3.59 (3H, s, OMe); $^{13}$C-NMR δ (CDCl$_3$) 171.9 (CO), 150.5, 149.5, 147.3, 146.4, 143.3 (C), 117.5 (C-1), 123.9, 120.9, 118.9, 112.5, 110.0, 100.6 (CH), 101.4 (OCH$_2$O), 55.9, 51.5 (2xOMe), 35.0 (CH$_2$); m/z (%) 316 (M$^+$, 100), 257 (52), 151 (91); IR ν 1735 cm$^{-1}$; Anal. Calcd. for C$_{17}$H$_{16}$O$_6$: C 64.55, H 5.10, found C 64.74, H 5.05.

Methyl 2-(2'-methoxyphenoxy)phenylacetate (5c). Syrup, 3.64 g, 67%; $^1$H-NMR δ (CDCl$_3$) 7.30-6.86 (7H, m, Ar-H), 6.70 (1H, m, Ar-H), 3.81 (3H, s, OMe), 3.77 (2H, s, CH$_2$), 3.63 (3H, s, OMe); $^{13}$C-NMR δ (CDCl$_3$) 171.9 (CO), 155.8, 151.5, 145.3 (C), 124.6 (C-1), 131.1, 128.4, 124.5, 122.7, 121.0, 120.6, 116.7, 112.7 (CH), 55.9, 51.8 (2xOMe), 35.6 (CH$_2$); m/z (%) 272 (M$^+$, 100), 213 (69), 197 (37), 181 (81); IR ν 1739 cm$^{-1}$; Anal. Calcd. for C$_{16}$H$_{16}$O$_4$ 1/2 H$_2$O: C 68.32, H 6.09, found C 68.38, H 6.25.

Aminolysis of esters 5a-c. Synthesis of amides 6a-c. A General procedure

A solution of 5a-c (12.0 mmol), sodium cyanide (0.058 g, 1.2 mmol) and methylamine (50 mL, 580 mmol) in methanol (100 mL) in a sealed round bottom flask was stirred at 60 °C (bath temperature). After 2 h, the methanol was removed in vacuo and the residue was dissolved in dichloromethane. This solution was washed with water, dried and evaporated to dryness to obtain 6a-c.

2-(2'-Methoxyphenoxy)-4,5-dimethoxy-$N$-methyl-phenylacetamide (6a). White solid, 3.42 g, 86%; mp 97-8 °C (EtOH); $^1$H-NMR δ (CDCl$_3$) 7.09-6.75 (5H, m, Ar-H), 6.40 (1H, s, Ar-H), 6.32 (1H, brs, NHCH$_3$), 3.84 (3H, s, OMe), 3.82 (3H, s, OMe), 3.68 (3H, s, OMe), 3.44 (2H, s, CH$_2$CO), 2.69 (3H, d, J=4.9, NHMe); $^{13}$C-NMR δ (CDCl$_3$) 149.9, 148.7, 147.5, 145.5, 145.3 (C), 117.3 (C-1), 124.0, 121.0, 118.2, 113.5, 112.3, 102.8 (CH), 56.1, 56.0, 55.9 (3xOMe), 38.1 (CH$_2$), 26.4 (NHMe); m/z (%) 331 (M$^+$, 89), 273 (62), 167 (100); IR ν 3324, 1646 cm$^{-1}$; Anal. Calcd. for C$_{18}$H$_{21}$NO$_6$: C 65.24, H 6.39, N 4.23, found C 65.15, H 6.41, N 4.13.

2-(2'-Methoxyphenoxy)-4,5-methylenedioxy-$N$-methyl-phenylacetamide (6b). White solid, 3.48 g, 92%; mp 125-7 °C (MeOH); $^1$H-NMR δ (CDCl$_3$) 7.13-6.81 (4H, m, Ar-H), 6.77 (1H, s, Ar-H), 6.31 (1H, brs, NHMe), 6.30 (1H, s, Ar-H), 5.87 (2H, s, OCH$_2$O), 3.81 (3H, s, OMe), 3.46 (2H, s, CH$_2$CO), 2.70 (3H, s, NHMe); $^{13}$C-NMR δ (CDCl$_3$) 171.6 (CO), 150.4, 149.2, 147.2, 144.8, 143.3 (C), 117.7 (C-1), 124.6, 121.1, 119.6, 112.5, 110.3, 99.3 (CH), 101.4 (OCH$_2$O), 55.9 (OMe), 35.2 (CH$_2$), 26.4 (NHMe); m/z (%) 315 (M$^+$, 90), 257 (54), 151 (100); IR ν 3428, 1649 cm$^{-1}$; Anal. Calcd. for C$_{17}$H$_{17}$NO$_5$: C 64.75, H 6.39, N 4.23, found C 65.15, H 6.41, N 4.13.

2-(2'-Methoxyphenoxy)-N-methyl-phenylacetamide (6c). White solid, 3.02 g, 93%; mp 83-4 °C (MeOH); $^1$H-NMR δ (CDCl$_3$) 7.30-6.90 (7H, m, Ar-H), 6.60 (1H, dd, J=8.0 and 1.0, Ar-H), 6.49 (1H, brs, NHMe), 3.76 (3H, s, OMe), 3.64 (2H, s, CH$_2$), 2.70 (3H, d, J=4.9, NHMe); $^{13}$C-
NMR δ (CDCl3) 171.4 (CO), 155.3, 150.9, 143.5 (C), 124.6 (C-1), 131.3, 128.3, 125.3, 122.7, 121.2, 121.2, 115.0, 112.5 (CH), 55.8 (OMe), 38.5 (CH₂), 26.3 (NHMe); m/z (%) 271 (M⁺, 100), 240 (19), 214 (75), 181 (80); IR ν 3261, 1644 cm⁻¹; Anal. Calcd. for C₁₆H₁₇NO₃: C 70.83, H 6.31, N 5.16, found C 70.78, H 6.26, N 5.05.

**Reaction of 6a with (COCl)₂**

An Ar degassed solution of 6a (0.022 g, 0.08 mmol) in dry CD₂Cl₂ (1 mL) was cooled at 0°C and oxalyl chloride (38 µL, 0.40 mmol) was added. After 2 min the ¹H-NMR spectrum shows the intermediate I with a small quantity of II. After 10 min at room temperature the solvent and the excess of reagent were removed under vacuum to obtain the alkylidene derivative II.

**I.** ¹H-NMR δ (CD₂Cl₂) 7.15-6.80 (4H, m, Ar-H), 6.75 (1H, s, Ar-H), 6.23 (1H, s, Ar-H), 4.05 (1H, d, J=16.0, CH₂CClO), 3.78 (3H, s, OMe), 3.76 (3H, s, OMe), 3.62 (1H, d, J=16.0, CH₂CClO), 3.61 (3H, s, OMe), 3.26 (3H, s, NHMe).

**II.** Yellow solid, 0.030 g, mp 206-8°C (CHCl₃/MeOH); ¹H-NMR δ (CDCl₃) 7.40 (1H, s, CH), 7.06-6.96 (2H, m, Ar-H), 6.85 (1H, t, J=8, Ar-H), 6.72 (1H, d, J=8, Ar-H), 6.43 (1H, s, Ar-H), 5.79 (1H, s, Ar-H), 3.90 (3H, s, OMe), 3.88 (3H, s, OMe), 3.73 (3H, s, OMe), 3.25 (3H, s, NHMe); ¹³C-NMR δ (CDCl₃) 154.5, 150.1, 149.7, 149.3, 148.5, 146.6, 145.6, 140.2, 124.0, 121.1, 118.3, 114.9 (C), 112.5, 111.3, 103.3, 85.5, 56.3 (OMe), 56.0 (2xOMe), 27.3 (NMe); m/z (%) 385 (M⁺, 80), 300 (49), 241 (100); IR ν 1808, 1686 cm⁻¹; UV (EtOH) (log ε) 384 (3.83), 254 (3.95) nm; Anal. Calcd. for C₂₀H₁₉NO₇·1/2 H₂O: C 60.91, H 5.11, N 3.55, found C 61.26, H 5.11, N 3.55.

**Reaction of 6a-c with (COCl)₂/SnCl₄. General procedure**

Over an Ar degassed solution of 6a-c (2 mmol) in dry dichloromethane (30 mL), oxalyl chloride (1.5 mL, 16 mmol) was added. The flask was sealed (septum) and heated at 70 °C, and stannyl chloride (1.4 mL, 11.3 mmol) was added. The reaction mixture was stirred at 20 °C for 5 h. After this period, it was diluted with dichloromethane and 2 M hydrochloric acid was added. The dichloromethane was separated and washed with 2 M hydrochloric acid and water. The organic layer was dried over MgSO₄ and concentrated in vacuo. The residue was separated by cc (CH₂Cl₂/MeOH, 100:0-100:2-100:15).

**Dioxocularine (7a).** Red crystals, 0.13 g, 18%; mp 214-8 °C (CHCl₃); [Lit.¹¹ 212-214 (EtOH)]; ¹H-NMR δ (CDCl₃) 8.03 (1H, d, J=8.8, H-5), 7.18 (1H, d, J=8.8, H-6), 6.90 (1H, s, H-5'), 6.67 (1H, s, H-2'), 6.62 (1H, s, H-α), 4.05 (3H, s, OMe), 3.92 (3H, s, OMe), 3.84 (3H, s, OMe), 3.66 (3H, s, NMe); ¹³C-NMR δ (CDCl₃) 175.2 (C-4), 156.7 (C-3, C-7), 151.1, 148.7, 146.6, 145.6, 140.2, 124.0, 105.0 (C-α), 56.6, 56.3, 56.3 (3xOMe), 33.0 (NMe); m/z (%) 367 (M⁺, 100), 339 (23), 324 (34); IR ν 1686, 1666 cm⁻¹; UV (EtOH) (log ε) 438 (3.48), 336 (3.73), 296 (3.65), 252 (3.83), 212 (4.20) nm.

**Aristolocularine (8a).** Red amorphous solid, 0.27 g, 40%; mp 180-3 °C [Lit.¹² 187-9 °C]; ¹H-NMR δ (CDCl₃) 7.30 (1H, d, J=8.3, Ar-H), 6.90 (1H, d, J=8.3, Ar-H), 6.57 (1H, s, Ar-H), 6.41
(1H, s, Ar-H), 5.65 (1H, s, H-α), 3.91 (3H, s, OMe), 3.86 (3H, s, OMe), 3.82 (3H, s, OMe), 3.21 (3H, s, NMe); 13C-NMR δ (CDCl3) 166.0 (CO), 151.5, 149.6, 147.1, 145.7, 141.7 (C-3', C-4', C-6, C-6', C-7), 136.4 (C-1), 127.4, 122.0, 118.9 (C), 118.5, 114.6, 113.5, 107.7 (CH), 106.6 (C-α), 56.5, 56.2, 56.1 (3xOMe), 25.6 (NMe); m/z (%) 339 (M+ 100), 324 (34), 296 (28); IR ν 1692, 1668 cm\(^{-1}\); UV (EtOH) (log ε) 410 (3.09), 282 (3.71), 206 (4.15) nm.

2,3,5-Trimethoxy-9-methylenechloroxanthene (9a). Brown solid, 0.26 g, 41%; mp 116-7 ºC (CHCl3, Z:E mixture, 3:1); 1H-NMR δ (CDCl3) Mayor isomer (Z), 7.93 (1H, s, H-1), 7.1-6.7 (4H, m, Ar-H), 6.33 (1H, s, =CHCl), 3.93, 3.90, 3.89 (3x3H, 3xs, 3xOMe); 13C-NMR δ (CDCl3) Mayor isomer (Z), 150.2, 148.1, 146.5, 144.4, 140.3, 126.6, 122.5, 110.9 (C), 123.2, 114.8, 110.6, 109.3, 108.3 (CH), 100.3 (CHCl), 56.2, 56.1, 56.0 (3xOMe); m/z (%) 320 (M+ 33), 318 (100), 303 (20); IR ν 1634 cm\(^{-1}\); Anal. Calcd. for C\(_{16}\)H\(_{11}\)NO\(_4\)\(_{35}\)Cl: C 64.06, H 4.74, found C 64.13, H 4.84.

O-Methyl-3,4-dioxo-dehydrocularicine (7b). Orange solid, 0.084 g, 12%; mp 283-90 ºC (CHCl3); 1H-NMR δ (CDCl3+TFA) 8.09 (1H, d, J=8.8, Ar-H), 7.26 (1H, d, J=8.8, Ar-H), 6.91 (1H, s, Ar-H), 6.80 (1H, s, Ar-H), 6.68 (1H, s, H-α), 6.02 (2H, s, OCH\(_2\)O), 4.07 (3H, s, OMe), 3.73 (3H, s, NMe); 13C-NMR δ (CDCl3+TFA) 175.2 (C-4), 158.4, 158.2 (C-3, C-7), 150.9, 149.9, 145.7, 140.2 (C-3', C-4', C-6', C-8), 132.9 (C-1), 129.8, 120.2 (C), 128.1, 120.7, 114.6, 108.1 (CH), 103.3 (C-α), 102.5 (OCH\(_2\)O), 56.9 (OMe), 33.8 (NMe); m/z (%) 351 (M+ 100), 323 (32); IR ν 1669 cm\(^{-1}\); UV (EtOH) (log ε) 436 (3.45), 326 sh (3.61), 296 (3.74), 266 sh (3.79), 248 sh (3.88), 206 (4.31) nm; Anal. Calcd. for C\(_{19}\)H\(_{13}\)NO\(_6\): C 64.96, H 3.73, N 3.99, found C 64.33, H 3.44, N 3.95.

O-Methyl-aristocularicine (8b). Yellow needles, 0.18 g, 28%; mp 234-8 ºC dec. (CHCl3); 1H-NMR δ (CDCl3) 7.32 (1H, d, J=8.1, Ar-H), 6.91 (1H, d, J=8.1, Ar-H), 6.59 (1H, s, Ar-H), 6.42 (1H, s, Ar-H), 5.93 (2H, s, OCH\(_2\)O), 5.64 (1H, s, H-α), 3.90 (3H, s, OMe), 3.20 (3H, s, NMe); 13C-NMR δ (CDCl3) 166.1 (CO), 151.8, 148.5, 148.1, 144.9, 141.4 (C-3', C-4', C-6, C-6', C-7), 136.5 (C-1), 128.0, 121.8, 120.8 (C), 118.9, 114.9, 109.4, 107.7 (CH), 104.4 (C-α), 101.9 (OCH\(_2\)O), 56.6 (OMe), 25.6 (NMe); m/z (%) 323 (M+ 100), 308 (7); IR ν 1705, 1655 cm\(^{-1}\); UV (EtOH) (log ε) 412 (3.27), 286 (3.86), 236 sh (3.89), 208 (4.08) nm; Anal. Calcd. for C\(_{18}\)H\(_{13}\)NO\(_5\): C 66.87, H 4.05, N 4.33, found C 66.33, H 3.44, N 3.95.

2,3-Methylenedioxy-5-methoxy-9-methylenechloroxanthene (9b). Brown solid, 0.26 g, 43%; mp 106-7 ºC (CHCl3, Z:E mixture, 3:2.5); 1H-NMR δ (CDCl3) Mayor isomer (Z), 7.82 (1H, s, H-1), 7.1-6.7 (4H, m, Ar-H), 6.32 (1H, s, =CHCl), 5.96 (2H, d, OCH\(_2\)O), 3.89 (3H, s, OMe); 13C-NMR δ (CDCl3) Mayor isomer (Z), 148.0, 147.8, 145.8, 143.2, 140.3, 122.6, 126.9, 112.0 (C), 123.4, 114.7, 110.7, 108.9, 106.0 (CH), 101.6 (OCH\(_2\)O), 98.4 (CHCl), 56.0 (OMe); m/z (%) 304 (M+ 33), 302 (100), 287 (47); IR ν 1630 cm\(^{-1}\); UV (CHCl3) (log ε) 342 (3.80), 296 sh (3.43), 268 sh (3.38), 250 (4.00) nm; Anal. Calcd. for C\(_{16}\)H\(_{11}\)O\(_4\)\(_{35}\)Cl: C 63.48, H 3.66, found C 63.56, H 3.73.

3',4'-Demethoxy-dioxocularine (7c). Yellow solid, 0.082 g, 15%; mp 222-6 ºC (CH\(_2\)Cl2); 1H-NMR δ (CDCl3) 8.02 (1H, d, J=8.8, Ar-H), 7.18 (1H, d, J=8.8, Ar-H), 7.36-7.16 (4H, m, Ar-H),
6.68 (1H, s, H-α), 4.04 (3H, s, OMe), 3.66 (3H, s, NMe); 13C-NMR δ (CDCl₃) 175.1 (C-4), 157.0, 156.8 (C-3, C-7), 154.9 (C-6'), 141.7 (C-8), 135.5 (C-1), 129.3, 128.3, 121.7 (C), 130.5, 129.9, 126.8, 121.4, 117.9, 113.9 (CH), 56.6 (OMe), 32.9 (NMe); m/z (%) 307 (M⁺, 100), 279 (93), 264 (45); IR ν 1668 cm⁻¹; UV (EtOH) (log ε) 398 sh (3.36), 332 (3.72), 286 sh (3.87), 256 sh (4.00), 216 (4.42) nm; Anal. Calcd. for C₁₈H₁₃NO₄: C 70.35, H 4.26, N 4.56, found C 70.30, H 4.30, N 4.60.

4',5'-Demethoxy-aristoyagonine (8c). Yellow needles, 0.11 g, 20%; mp 132–5 ºC (CHCl₃); 1H-NMR δ (CDCl₃) 7.28 (1H, d, J=8.4, Ar-H), 7.1-6.9 (4H, m, Ar-H), 6.89 (1H, d, J=8.4, Ar-H), 5.70 (1H, s, H-α), 3.89 (3H, s, OMe), 3.20 (3H, s, NMe); 13C-NMR δ (CDCl₃) 166.2 (CO), 153.5, 151.8 (C-6, C-6'), 141.7 (C-7), 137.5 (C-1), 127.6, 127.2, 121.9 (C), 131.3, 129.6, 125.2, 122.3, 118.5, 114.9 (CH), 107.7 (C-α), 56.7 (OMe), 25.6 (NMe); m/z (%) 279 (M⁺, 100), 264 (31), 236 (24); IR ν 1699, 1663 cm⁻¹; UV (EtOH) (log ε) 394 (3.64), 306 sh (4.07), 290 (4.27), 248 (4.24), 222 (4.21) nm; Anal. Calcd. for C₁₇H₁₃NO₃: C 73.11, H 4.69, N 5.01, found C 72.80, H 4.59, N 4.92.

4',5'-Demethoxy-1,α-dihydro-aristoyagonine (12c). Yellow-brown crystals, 0.14 g, 25%; mp 169-171 ºC (EtOH); 1H-NMR δ (CDCl₃) 7.49 (1H, d, J=8.3, Ar-H), 7.32-6.95 (5H, m, Ar-H), 4.50 (1H, dd, J=11.3 and 2.7, H-1), 3.95 (3H, s, Me), 3.41 (1H, dd, J=13.6 and 2.7, HCH), 3.14 (3H, s, NMe), 2.87 (1H, brt, J=13.6, HCH); 13C-NMR δ (CDCl₃) 167.9 (CO), 154.0, 151.7, 139.3, 132.8, 124.5, 123.1 (C), 132.5, 128.6, 123.3, 121.7, 118.1, 112.3 (CH), 59.7 (OMe), 56.6 (C-1), 38.0 (CH₂), 27.2 (NMe); m/z (%) 281 (M⁺, 100), 250 (47), 175 (45); IR ν 1688 cm⁻¹; UV (CHCl₃) (log ε) 294 sh (3.47), 266 (4.33), 244 (4.34) nm; Anal. Calcd. for C₁₇H₁₅NO₃: C 73.57, H 5.38, N 4.98, found C 72.54, H 5.18, N 4.72.

Reaction of chloroxanthene 9b with Mg/THF
Over a solution of 9b (0.040 g, 0.13 mmol) in THF (3 mL) was added Mg (4 mg, 0.16 mmol). After refluxing for 12 h, the solution was diluted with wet THF and filtered. The filtrates were washed with water, dried and concentrated in vacuo to obtain 10b. This compound decomposes in air to 11b.

2,3-Methylenedioxy-5-methoxy-9-methylenexanthene (10b). Syrup, 0.035 g, quantitative; 1H-NMR δ (CDCl₃) 7.28 (1H, d, J=8.0 and 1.2, Ar-H), 7.08 (1H, s, Ar-H), 7.02 (1H, t, J=8.0, H-7), 6.85 (1H, dd, J=8.0 and 1.2, Ar-H), 6.74 (1H, s, Ar-H), 5.96 (2H, s, OCH₂O), 5.34 (1H, s, HCH), 5.24 (1H, s, HCH), 3.92 (3H, s, OMe); 13C-NMR δ (CDCl₃) 148.7, 148.2, 145.8, 144.5, 132.4, 121.5, 114.0 (C), 101.9 (OCH₂O), 98.6 (C=CH₂), 122.8, 115.4, 110.8, 101.9, 98.6 (CH), 56.1 (OMe); m/z (%) 268 (M⁺, 100), 253 (32); IR ν 1632 cm⁻¹, UV (CHCl₃) (log ε) 346 (3.50), 304 (3.56), 250 (4.04) nm; HRMS calcd. for C₁₆H₁₂O₄ (M⁺) m/z 268.0736, found 268.0735.

2,3-Methylenedioxy-5-methoxyxanthone (11b). Brown solid; mp 196-8 ºC; 1H-NMR δ (CDCl₃) 7.89 (1H, m, Ar-H), 7.64 (1H, s, Ar-H), 7.33-7.18 (2H, m, Ar-H), 7.02 (1H, s, Ar-H), 6.11 (2H, s, OCH₂O), 4.02 (3H, s, OMe); 13C-NMR δ (CDCl₃) 175.9 (CO), 153.7, 153.6, 148.4, 146.4, 145.4 (C), 122.2, 116.4 (C-8a, C-1a), 123.4, 117.5, 114.7, 103.0, 98.2 (CH), 102.4 (OCH₂O), 56.4 (OMe); m/z (%) 270 (M⁺, 100), 255 (50); IR ν 1651 cm⁻¹, UV (log ε) 358 (3.35), 312 (3.20), 252 (3.90) nm; HRMS calcd. for C₁₅H₁₀O₅ (M⁺) m/z 270.0528, found 270.0521.
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