Available online at www.sciencedirect.com
SCIENCE DIRECT®
Tetrahedron Letters 46 (2005) 5033–5037
Tetrahedron Letters

Synthesis of novel triketone-based acidichromic colorants

Ching-Tsan Lin, Jen-Hao Shih, Chung-Ling Chen and Ding-Yah Yang*

Department of Chemistry, Tunghai University, 181, Taichung-Kang Rd. Sec.3, Taichung 407, Taiwan

Received 11 April 2005; revised 13 May 2005; accepted 18 May 2005
Available online 9 June 2005

Abstract—This letter presents the synthesis and evaluation of two novel triketone-containing acidichromic colorants. Analysis results indicate that both prepared triketone-containing compounds undergo two distinct and reversible color changes under both strongly acidic and basic conditions. Thus, a pH sensitive triketone functional group is introduced for the first time to design and synthesize acidichromic colorants.

1. Introduction

Research on the relation between color and structure in organic compounds has received a great deal of attention for decades.[1–3] Compounds exhibiting reversible color changes depending on either the pH in the solution or on alternating exposure to HCl and NH_3 in films are called acidichromic colorants.[4–10] Acidichromic colorants are highly promising for use in pH sensors, photo-, and chemical-switching systems, as well as gas controlled reversible color-change devices. Given that most reported acidichromic colorants contain only one pH-sensitive functional group in molecules, their color changes are limited to a narrow pH range. Therefore, acidichromic colorants seldom change their color under both extremely high and low pH values. The absence of two or more distinct color changes in both acidic and basic conditions limits applications of phenol or aniline-containing acidichromic colorants. Thus, novel acidichromic colorants that respond to strong acidic and basic conditions are highly desired for both academic and industrial purposes. To meet this end, new functionalities must be explored to serve as pH-sensitive groups as an alternative for existing phenols and aromatic amines in acidichromism. In this letter, we reported rational design and chemical synthesis of two novel acidichromic colorants by combination of a pH-sensitive triketone-containing functional group with an aniline-containing molecule. The resulting compounds underwent two distinct and reversible color changes under both acidic and basic conditions.

2. Results and discussion

Previous studies have demonstrated that the triketone functional group in 2-benzoyl-1,3-cyclohexanedione is coplanar,[11] owing to the conjugation of C-2 carbonyl moiety with the cyclohexene ring system by an intramolecular hydrogen bond of the C-3 hydroxyl hydrogen to the oxygen atom of C-2 carbonyl group, as shown in Figure 1. After deprotonation of C-3 hydroxyl group, however, the intramolecular hydrogen bond is disrupted. The subsequent intrinsic electrostatic repulsion between the 2-acyl oxygen atom and the two 1,3-diketone oxygens causes deformation of the molecule from planarity. This observation suggested that the triketone moiety of 2-benzoyl-1,3-cyclohexanedione is coplanar under neutral conditions, but is deformed from planarity when the hydroxyl group is deprotonated under basic conditions, due to the electrostatic repulsion between the carbonyl oxygen and the negatively charged oxygen

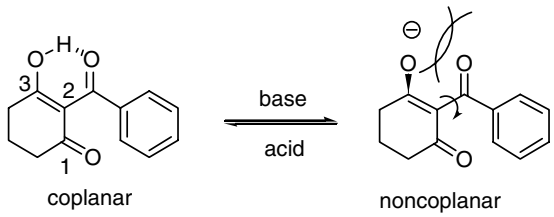


Figure 1.

Keywords: Triketone; Acidichromic colorant.
* Corresponding author. Tel.: +886 4 2359 7613; fax: +886 4 2359 0426; e-mail: yang@mail.thu.edu.tw

0040-4039/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tetlet.2005.05.070

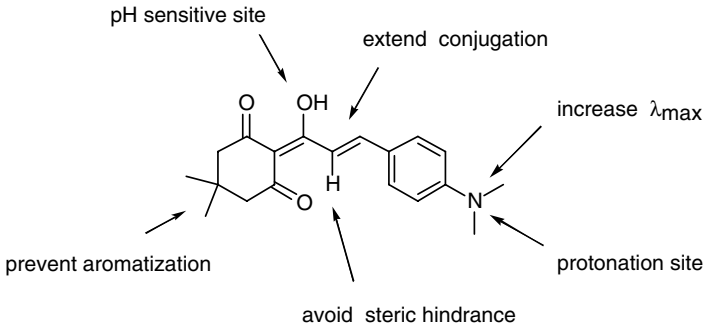
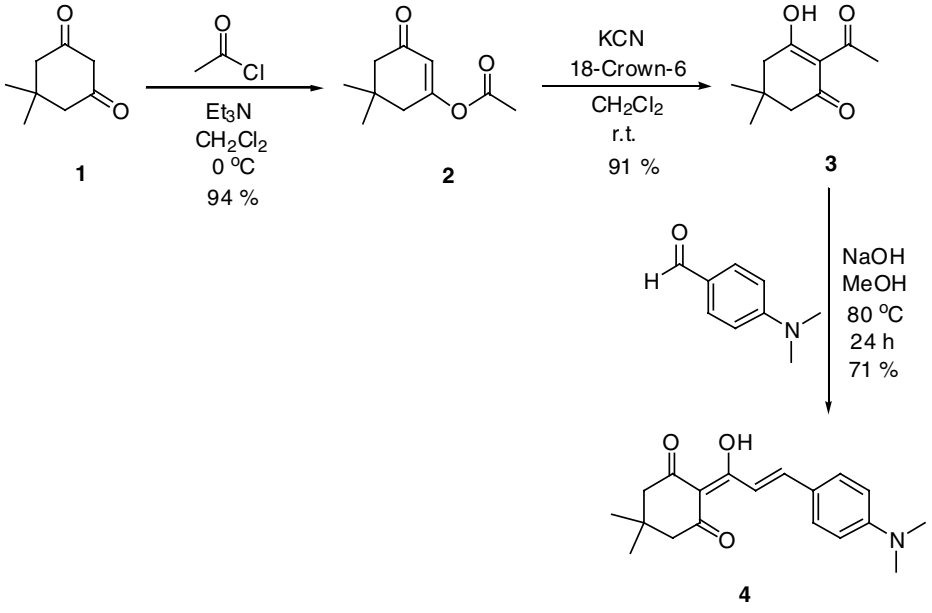


Figure 2.

atom. Thus, the conformation of triketone-type compounds can be regulated by protonation/deprotonation of the enolic hydrogen at the C-3 position.

Figure 2 shows the structure of the designed potential acidichromic colorant. Two dimethyl groups on the six-membered ring at the left hand side of the molecule were incorporated to prevent the possible oxygen-promoted aromatization. The double bond in the middle of the molecule extended the conjugation and avoided the steric hindrance between the carbonyl group and hydrogen atoms on the benzene ring. The *N*,*N*-dimethylamino group at the *para* position of benzene ring not only increased the molecule's UV absorption wavelength to the desired visible ranges under neutral conditions, but also provided a protonation site under acidic conditions. Scheme 1 outlines the straightforward preparation of the target molecule **4**. The synthesis started with esterification of dimedone **1** with acetyl chloride in methylene chloride using triethylamine as a base, followed by a potassium cyanide-catalyzed isomerization[12] to 2-acetylcyclohexane-1,3-dione **3**. The subsequent base-catalyzed aldol condensation of **3** with 4-*N*,*N*-dimethylaminobenzaldehyde in methanol afforded the target **4**[13] with an overall yield of 60%. The structure of **4** was confirmed by X-ray crystallography as shown in Figure 3.

With the availability of **4**, the acidichromic behavior in both strong acids and bases was then determined. Under neutral pH conditions in methylene chloride, compound **4** exhibited a red color due to the extended conjugation with a UV absorption λ_{max} value of 463 nm. When gaseous hydrochloric acid was bubbled through the solution, it turned colorless instantly owing to protonation of the nitrogen atom. When treated with a strong base, that is, sodium methoxide or sodium hydride, compound **4** turned yellow immediately owing to the expected conjugation disruption. The proposed acidichromic switch of **4** is shown in Scheme 2, and their corresponding UV absorption spectra in both acidic and basic conditions are depicted in Figure 4 with the λ_{max} values of 343 and 390 nm, respectively. Figure 5 showed the UV absorption changes of **4** when titrated with different concentrations of NaOMe in methylene chloride. An isosbestic point was observed at 414 nm, which suggests interconversion of neutral and deprotonated forms



Scheme 1.

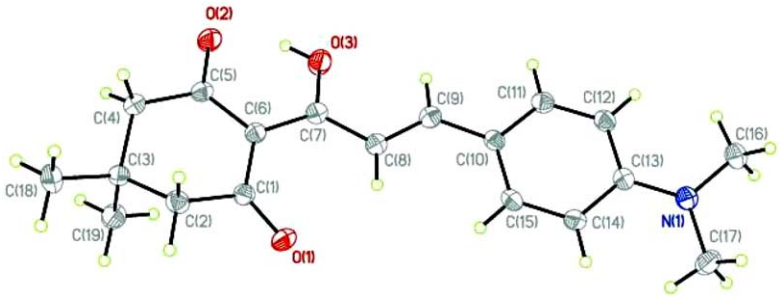
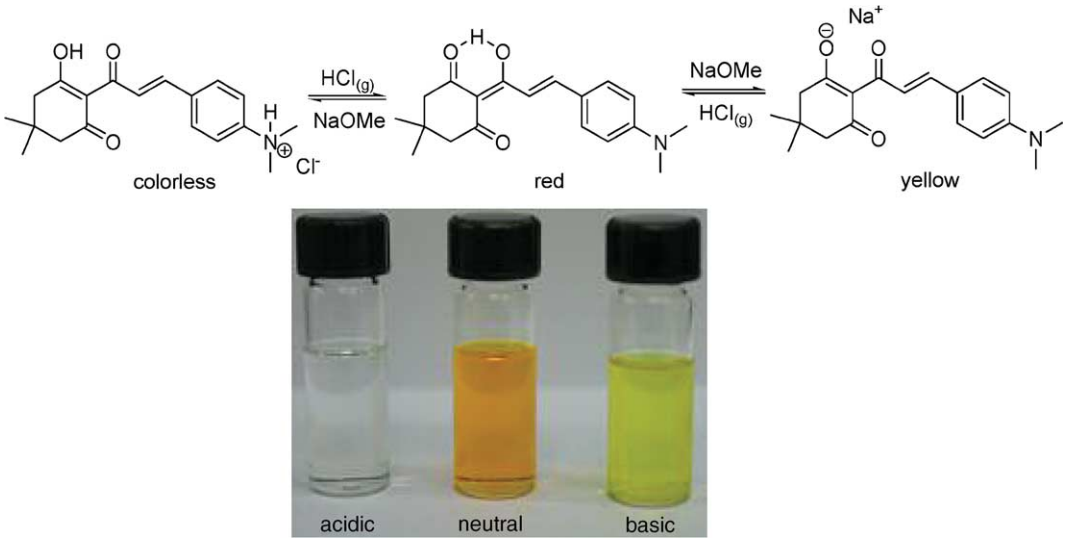


Figure 3. X-ray crystal structure of **4**.



Scheme 2. The acidichromic switch of **4** and the corresponding colors in acidic, neutral, and basic conditions.

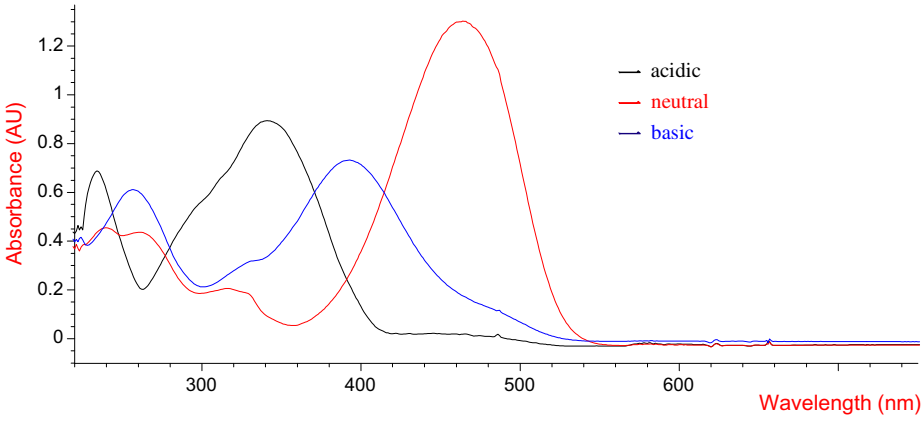


Figure 4. UV spectra of **4** in neutral, acidic, and basic conditions.

of **4**. The reversible acidichromic process was repeated 10 times without significant changes in the UV spectra by sequentially exposing **4** with an acid–base–base–acid sequence, as shown in Figure 6.

The fact that compound **4** failed to change color when gaseous ammonia was bubbled vigorously through the solution suggested that the enolic hydrogen is too stable to be deprotonated by ammonia. The failure to response to gaseous ammonia deterred **4** from being applied in gas controlled reversible color-change devices. Thus, the dimedone moiety in **4** was replaced with the 4-hydroxycoumarin moiety in an effort to adjust the relative stability of the intramolecular hydrogen bonding. The resulting coumarin-containing compound **5** was prepared by the same procedure as that of **4** except that the Dean–Stark trap with piperidine in benzene was used in the final aldol condensation step.[14]

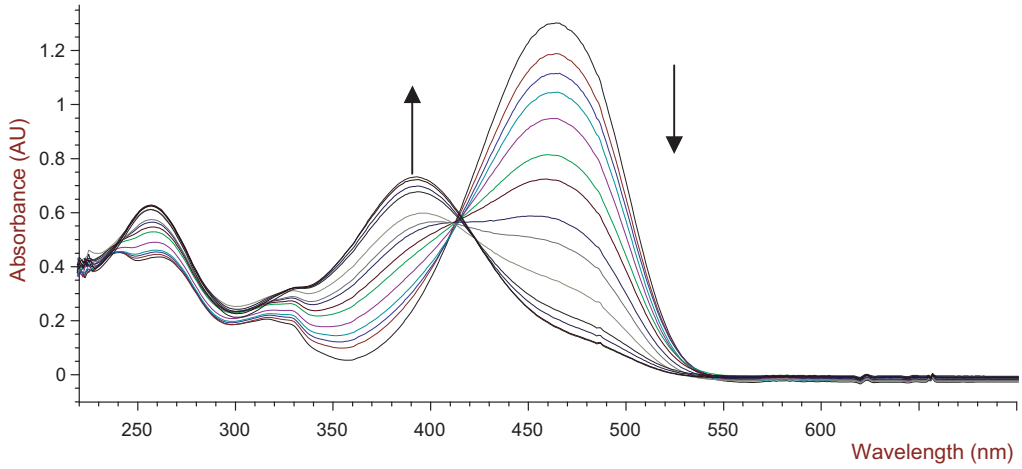


Figure 5. UV curves of titration **4** (2.7×10^{-5} M) with increasing concentrations of NaOMe in CH_2CH_2.

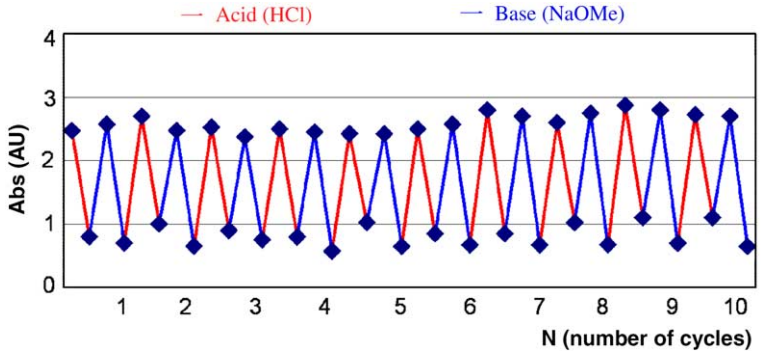
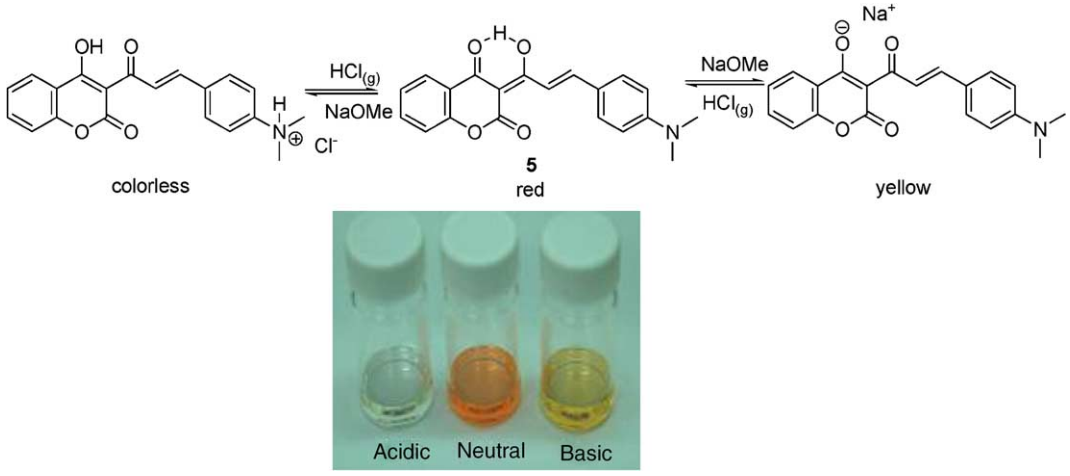


Figure 6. Reversible acidichromic behaviors of **4**. Optical density variations at neutral (463 nm), acidic (343 nm), and basic (390 nm) conditions during sequentially exposing **4** with an acid–base–base–acid sequence in CH_2Cl_2 for 10 cycles.

Compound **5** resembled **4** in acidichromism when treated with strong acids and bases, as outlined in Scheme 3. Upon bubbling of gaseous ammonia, however, compound **5** did reveal a color change from red to pink. The observation of two λ_{max} values at 502 and 398 nm in UV spectra, shown in Figure 7, indicated that approximately two thirds of the enolic hydrogens were deprotonated by ammonia and the rest of them remained intact. Thus, the combination of red and yellow gave **5** the color of pink. This result demonstrated that **5** displayed weaker intramolecular hydrogen bonding than that of **4**. Presumably, the relative strength of the intramolecular hydrogen bond in **5** can be further adjusted by incorporating various electron-withdrawing substitutents on benzene ring of the coumarin moiety.



Scheme 3. The acidichromic switch of **5** and the corresponding colors in acidic, neutral, and basic conditions.

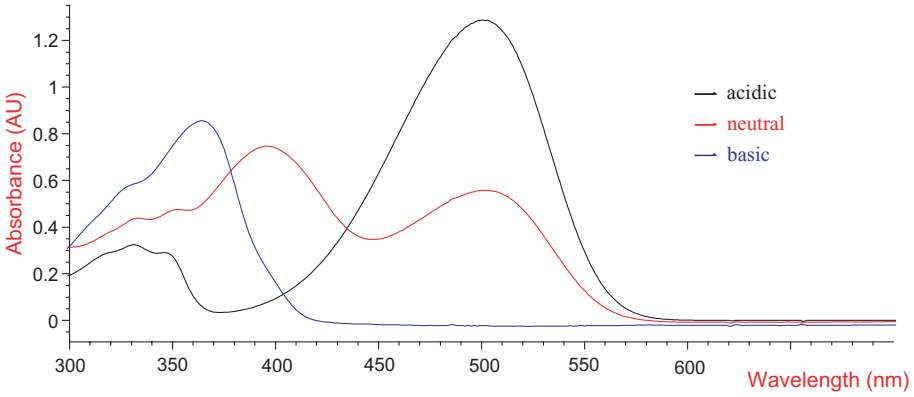


Figure 7. UV spectra of **5** in neutral, acidic, and basic (gaseous ammonia) conditions.

3. Conclusions

A unique property of triketone functional group, that is, sensitivity to pH, has been introduced for the first time in the design and synthesis of two novel acidichromic colorants. Both acidichromic colorants contain two pH-sensitive functional groups and exhibit reversible color changes from red to yellow under high pH conditions and to colorless under low pH conditions. These molecules may potentially function as pH sensors or for use in chemical-switching systems. Further incorporation of electron withdrawing substituents like halogens on the coumarin moiety of **5** to tune finely the acidichromic property is currently underway.

Acknowledgments

The authors would like to thank the National Science Council of Republic of China, Taiwan for financially supporting this research under Contract No. NSC 93-2113-M-029-002. The referees are also appreciated for their valuable comments.

References and notes

1. Christie, R. M. *Colour Chemistry*; Royal Society of Chemistry: Cambridge, 2001.
2. Daehne, S.; Leupold, D. *Angew. Chem., Int. Ed. Engl.* **1966**, *5*, 984–993.
3. Daehne, S.; Leupold, D.; Radeglia, R. *J. Prakt. Chem.* **1972**, *314*, 525–531.
4. Yin, M.; Gong, H.; Zhang, B.; Liu, M. *Langmuir* **2004**, *20*, 8042–8048.
5. Siri, O.; Braunstein, P.; Rohmer, M. M.; Benard, M.; Welter, R. *J. Am. Chem. Soc.* **2003**, *125*, 13793–13803.
6. Luo, Q.; Li, X.; Jing, S.; Zhu, W.; Tian, H. *Chem. Lett.* **2003**, *32*, 1116–1117.
7. Gong, H.; Wang, C.; Liu, M.; Fan, M. *J. Mater. Chem.* **2001**, *11*, 3049–3052.
8. Miliani, C.; Romani, A.; Favaro, G. *J. Phys. Org. Chem.* **2000**, *13*, 141–150.
9. Pina, F.; Melo, M. J.; Maestri, M.; Ballardini, R.; Balzani, V. *J. Am. Chem. Soc.* **1997**, *119*, 5556–5561.
10. Sun, X. D.; Fan, M. G.; Meng, X. J.; Knobbe, E. T. *J. Photochem. Photobiol. A* **1997**, *102*, 213–216.
11. Wu, C. S.; Huang, J. L.; Sun, Y. S.; Yang, D. Y. *J. Med. Chem.* **2002**, *45*, 2222–2228.
12. Montes, I. F.; Burger, U. *Tetrahedron Lett.* **1996**, *37*, 1007–1010.
13. For preparation of **4**: To a solution of **3** (1.82 g, 10 mmol) and 4-dimethylaminobenzaldehyde (1.49 g, 10 mmol) was added 2 N NaOH/MeOH (30 mL). This mixture was then gently heated to 80 °C for 24 h. After completion of the reaction, the solvent was concentrated in vacuo. This dark red mixture was poured into water. The solution was then extracted with dichloromethane twice. The combined organic extracts were dried over $MgSO_4$, filtered, and concentrated. The crude product was purified by column chromatography (EtOAc–hexanes = 1:9) to give a red solid **4** in 71% yield. Mp 154–155 °C. ^{1}H NMR ($CDCl_3$, 300 MHz) δ 18.49 (d, J = 0.9 Hz, 1H), 8.17 (dd, J = 15.6, 0.9 Hz, 1H), 8.12 (d, J = 15.6 Hz, 1H), 7.60–7.55 (m, 2H), 6.69–6.64 (m, 2H), 3.06 (s, 6H), 2.54 (s, 2H), 2.42 (s, 2H), 1.09 (s, 6H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 201.8, 196.1, 186.7, 152.5, 147.9, 131.5, 122.9, 116.3, 111.7, 110.2, 53.3, 49.2, 40.1, 30.4, 28.3. IR (KBr) ν 2956, 1649, 1583, 1534, 1420, 1373, 1280, 1162, 959, 819 cm^{-1}. HRMS (EI) calcd for $C_{19}H_{23}NO_3$ (M^+), 313.1678, found 313.1679. Crystallographic data (excluding structure factors) for **4** have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication number CCDC-270989. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif, or by emailing data_request@ccdc.cam.ac.uk, or by contacting The Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge CB2 1EZ, UK; Fax: +44 1223 336033.
14. For preparation of **5**: To a solution of 3-acetyl-4-hydroxychromen-2-one (100 mg, 0.5 mmol) and 4-dimethylaminobenzaldehyde (746 mg, 0.5 mmol) in benzene (25 mL) was added piperidine (50 mg, 0.5 mmol). This mixture was refluxed in a Dean–Stark trap. After completion of the reaction within 6 h, the solvent was concentrated in vacuo. This mixture was poured into water. The solution was then extracted with dichloromethane twice. The combined organic extracts were dried over $MgSO_4$, filtered, and concentrated. The crude product was purified by column chromatography (EtOAc–hexanes = 3:7) to give a dark solid **5** in 78% yield. Mp 145–146 °C. ^{1}H NMR ($CDCl_3$, 300 MHz) δ 19.23 (s, 1H), 8.25 (d, J = 15.3 Hz, 1H), 8.12 (d, J = 15.3 Hz, 1H), 8.09 (dd, J = 7.8, 1.8 Hz, 1H), 7.65 (dd, J = 9.0, 1.8 Hz, 1H), 7.64 (td, J = 6.0, 1.8 Hz, 2H), 7.30 (td, J = 9.9, 2.7 Hz, 2H), 6.70 (d, J = 9.0 Hz, 2H), 3.09 (s, 6H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 207.0, 190.3, 174.5, 173.6, 163.0, 135.3, 131.7, 125.7, 124.0, 122.3, 121.8, 115.6, 112.2, 111.2, 111.5, 110.9, 93.5, 40.1. IR (KBr) ν 2937, 1594, 1164, 814, 757 cm^{-1}. HRMS (EI) calcd for $C_{20}H_{17}NO_4$ (M^+), 335.1158, found 335.1163.