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Structure, reactivity, and application of some triketone derivatives

You-Sheng Chen, Pei-Yu Kuo, Tien-Lan Shie and Ding-Yah Yang*

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

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Abstract—The major tautomer of several triketone derivatives in organic and aqueous solutions has been determined. Their solvent- and base-sensitive properties have been applied in the design of a polarity-sensitive fluorescent probe and an acidichromic colorant, respectively. The regioselective acetylation and methylation of 2-acyldimedone, 3-acyl-4-hydroxycoumarin, and 2-acyl-1,3-indandione have also been investigated. The results indicated that acetylation and methylation of the first two occurred specifically at endocyclic enolic oxygens, whereas for the latter they occurred at exocyclic enolic oxygen.

1. Introduction

Triketones and their derivatives have long been known for their extensive application as biologically active substances. For instance, nitisinone has been used as a therapeutic agent for the treatment of tyrosinaemia type I disease;[1] sethoxydim, an oxime derivative of triketone, is a herbicide that is used for the control of grasses in broadleaf crops (Fig. 1).[2] Therefore, understanding the structure and reactivity of triketone derivatives is crucial for further developments of other important biologically active molecules. While up to five tautomers are possible for a single triketone compound, the distributions of these tautomers are highly dependent on both molecular structures and surrounding solvent systems. For instance, although previous studies have demonstrated that both 2-acyldimedone and 2-acyl-4-hydroxycoumarin mainly exist in endocyclic enol forms in solid states,[3] the major tautomer of these triketones present in solution is highly dependent on solvent polarity, that is, the major tautomer of 2-acetyldimedone in relatively nonpolar organic solvents such as hexane and chloroform is in the endocyclic enol form, and the major tautomer in polar protic solvents like methanol or aqueous solution mainly presents in the exocyclic enol form.[4] A similar observation is also made of 2-acetyl-4-hydroxycoumarin,[5] as indicated in Scheme 1. Here we report the determination of major tautomers of several triketone derivatives in organic and aqueous solutions. Both solvent- and base-sensitive properties of these triketones have been applied in the design and synthesis of a potential polarity-sensitive fluorescent probe and an acidichromic colorant, respectively. Furthermore, the regioselective reactions of some triketones i.e. 2-acyldimedone, 3-acyl-4-hydroxycoumarin, and 2-acyl-1,3-indandione toward acetylation and methylation have also been investigated. Some of the results have been previously communicated.[6,11]

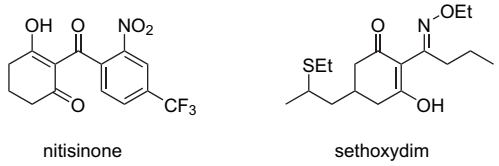
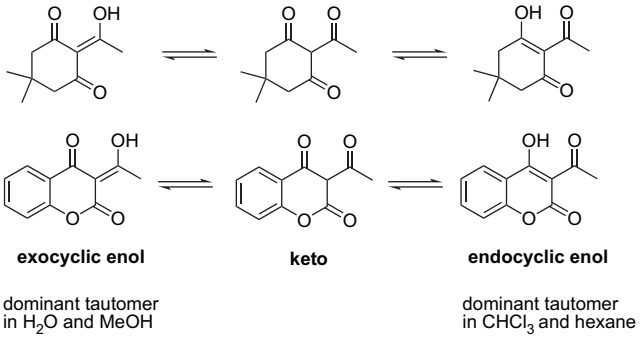


Figure 1. The structures of two biologically active triketone derivatives.



Scheme 1. The major tautomer of 2-acetyldimedone and 2-acetyl-4-hydroxycoumarin exists in polar protic and nonpolar solvents.

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

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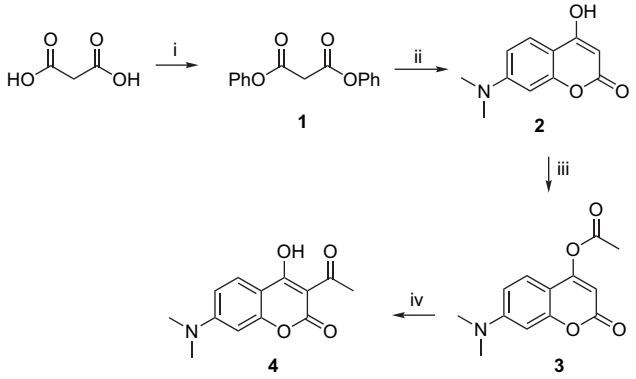
2. Results and discussion

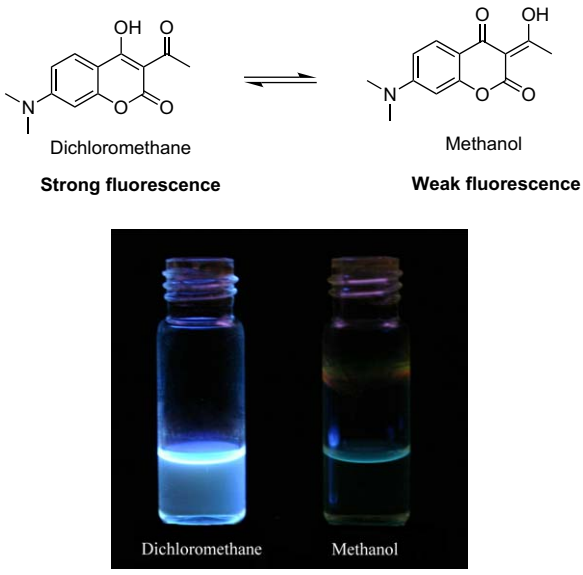
Since 2-acetyl-4-hydroxycoumarin itself is weakly fluorescent, an *N*,*N*-dimethylamino group was incorporated at 7-position of the coumarin moiety in an effort to enhance its fluorescence property. The proposed compound **4** was prepared in four steps as outlined in Scheme 2. It started with esterification of malonic acid with phenol in the presence of phosphorus oxychloride to give the diester **1**.[7] The diester **1** was then coupled with 3-*N*,*N*-dimethylaminophenol in toluene to afford 7-*N*,*N*-dimethylamino-4-hydroxycoumarin **2**.[8] Esterification of **2** with acetyl chloride in the presence of triethylamine as a base yielded ester **3**. Final isomerization was achieved by treating **3** with a catalytic amount of potassium cyanide and 18-crown-6 in methylene chloride to afford the target molecule **4**.



Scheme 2. Reagents and conditions: (i) $POCl_3$, phenol, 115 °C, 1.5 h; (ii) 3-dimethylaminophenol, toluene, reflux, 7 h; (iii) acetyl chloride, Et_3N, CH_2Cl_2, 0 °C, 0.5 h; (iv) KCN, Et_3N, 18-crown-6, CH_2Cl_2, rt, 72 h.

The synthesized compound **4** exists mainly in the endocyclic enol form in organic solvents like methylene chloride and is highly fluorescent due to the presence of an *N*,*N*-dimethylamino group. Essentially no fluorescence was detected when **4** was dissolved in protic solvents like methanol, where it exists mainly in the exocyclic enol form (Scheme 3). Figure 2 shows the UV absorption spectra of **4** in various compositions of methanol and methylene chloride. Two isosbestic points were observed at 300 and 350 nm, which suggest interconversion of two different tautomeric forms. The fluorescence quantum yield of **4** in various solvents was also determined as indicated in Table 1. Up to 30 times difference between the highest fluorescence quantum yield of **4** in benzene (Φ_f=0.91) and the lowest fluorescence quantum yield in water (Φ_f=0.03) was observed.

Since the energy difference between exocyclic and endocyclic enols of 2-acetyl-4-hydroxycoumarin has been calculated to be merely 1 kcal/mol,[5] we speculated that the major tautomer of 2-acyldimedone in nonpolar organic solutions can be switched from the endocyclic enol form to the exocyclic enol one by a simple conjugation extension of the triketone moiety. The extension of conjugation was easily accomplished by a base-catalyzed condensation of 2-acetyldimedone with 4-*N*,*N*-dimethylaminobenzaldehyde to yield compound **5** (Scheme 4). The observation of a long range coupling with a coupling constant of 0.9 Hz between the enolic hydrogen and the adjacent vinyl hydrogen on



Scheme 3. The major tautomers of compound **4** in CH_2Cl_2 and CH_3OH, and their fluorescence difference.

proton NMR spectra in deuterated chloroform confirmed that **5** exists in the more conjugated exocyclic enol form in nonpolar organic solvents. This result suggested that the dominant tautomer of triketone derivatives can be easily shifted from one to the other by introducing an extra functional group adjacent to it. A similar extension of conjugation of 2-acetyl-4-hydroxycoumarin also switched the major tautomer to the expected exocyclic enol **6** (Scheme 4).

In addition to possessing polarity-sensitive property, some triketones are also sensitive to bases. For instance, the triketone functional group in 2-acyl-1,3-cyclohexanedione is coplanar,[3a] owing to the conjugation of C-2 carbonyl moiety with the cyclohexene ring system by an intramolecular hydrogen bond between the C-3 hydroxyl hydrogen and the oxygen atom of C-2 carbonyl group. After deprotonation of C-3 hydroxyl group by a base, 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 base-sensitive property of triketones has been recently applied in the design and synthesis of an acidichromic colorant, which can undergo two distinct and reversible color changes under both strongly acidic and basic conditions (Scheme 5).[6]

In the case of 2-acyl-1,3-indandione, three tautomers are also possible for this benzene-fused triketone (Scheme 6). The crystal structure of 2-acetyl-1,3-indandione[9] has been determined to be in the exocyclic enol form in the solid state, with the enolic hydrogen external to the indan system, thus the indan portion is essentially planar. This exocyclic enol form is also the major tautomer in solutions and is not solvent-sensitive. The reason why this particular configuration is favored over the other possible endocyclic enol tautomer is currently not clear, presumably due to the antiaromatic nature of the latter.[10]

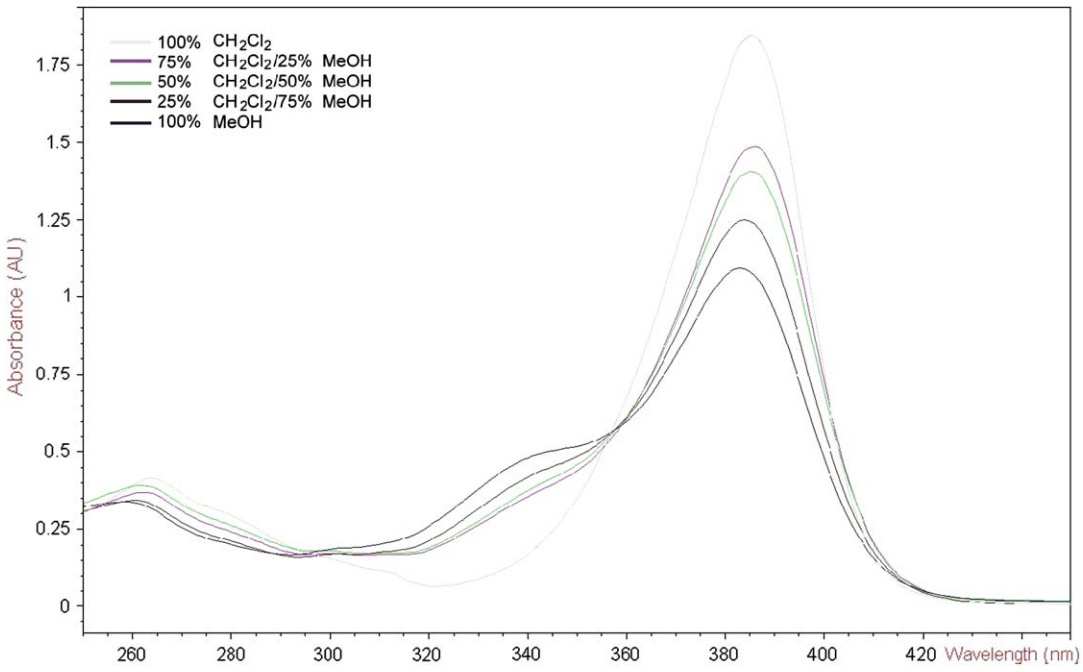


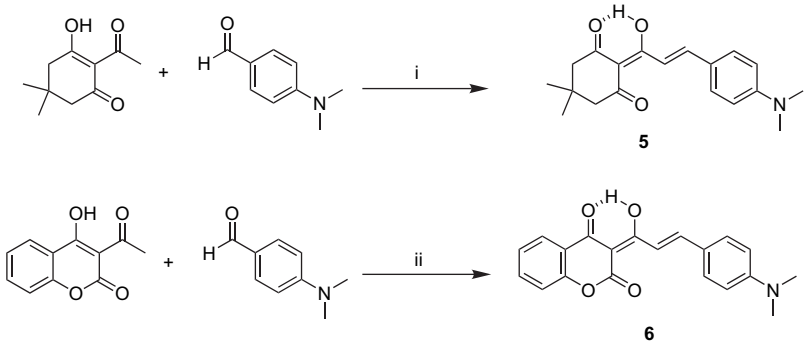
Figure 2. UV absorption spectra of **4** in various compositions of methanol and methylene chloride.

Table 1. The fluorescence quantum yield of **4** in various solvents

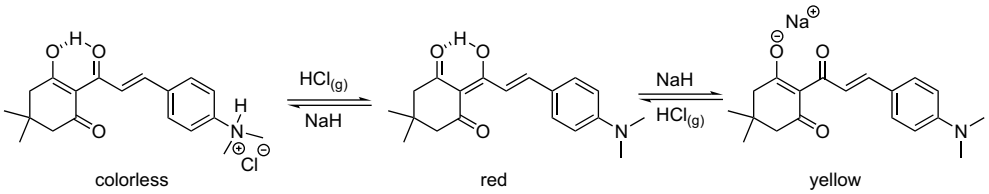
Solvent	λ_{ex} (nm)	λ_{em} (nm)	Quantum yield (Φ_f)
Benzene	385	407	0.91
Hexane	375	384	0.90
Toluene	385	405	0.86
CH_2Cl_2	385	418	0.85
$CHCl_3$	385	414	0.82
EtOAc	385	418	0.41
THF	385	420	0.31
Acetone	385	429	0.04
EtOH	385	424	0.04
CH_3CN	385	433	0.03
CH_3OH	345	421	0.03
DMF	389	418	0.03
H_2O	345	427	0.03

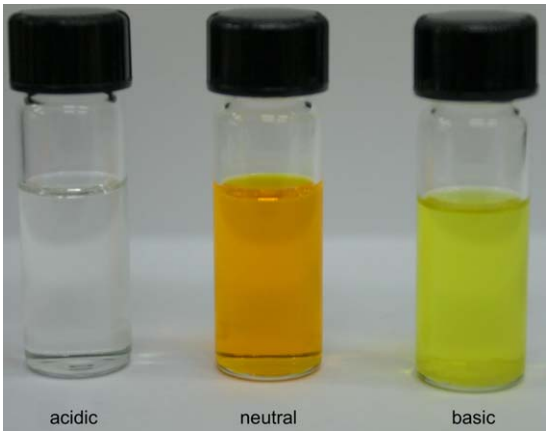
Acetylation of 2-acetyl-1,3-cyclohexanedione with acetyl chloride under basic conditions occurs specifically at 3-enolic oxygen to give the enol ester **7**. The electrostatic repulsion between the 2-acyl oxygen atom and the two 1,3-diketone oxygens of the resulting enol ester caused deformation of the triketone functional group from planarity. This repulsion can be easily relieved via enolization of the 2-acyl group of **7**, followed by a 1,5-acyl transfer reaction to afford enol acetate **8**. The resulting **8** can then undergo esterification again to obtain enol diacetate **9**. Thus, with available α-hydrogens on the 2-acyl group, this intrinsic repulsion presumably provides a driving force for enol ester **7** to undergo enolization and subsequent isomerization.[11] A similar rearrangement was also observed for 3-acyl-4-hydroxycoumarin to afford **12**, as shown in Scheme 7.

Acetylation of 2-acyl-1,3-indandione by ketene[12] or acetyl chloride, however, occurred selectively at C-2 hydroxyl group to give the only product **13** quantitatively (Scheme 8). The enol ester **13** is unstable and prone to be hydrolyzed in the aqueous solution due to the previously described electrostatic repulsion between the two oxygens. It, however, has lower energy than the undetected enol ester **14**, presumably because **14** is further destabilized by the proposed antiaromatic nature. No further rearrangement of **13** was observed.

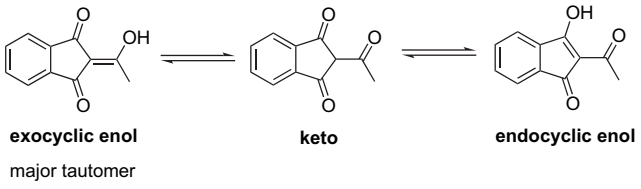


Scheme 4. Shifting the endocyclic enol tautomer to exocyclic enol tautomer by extension of conjugation. Reagents and conditions: (i) NaOH, MeOH, 80 °C, 24 h; (ii) piperidine, benzene, reflux, Dean–Stark trap.



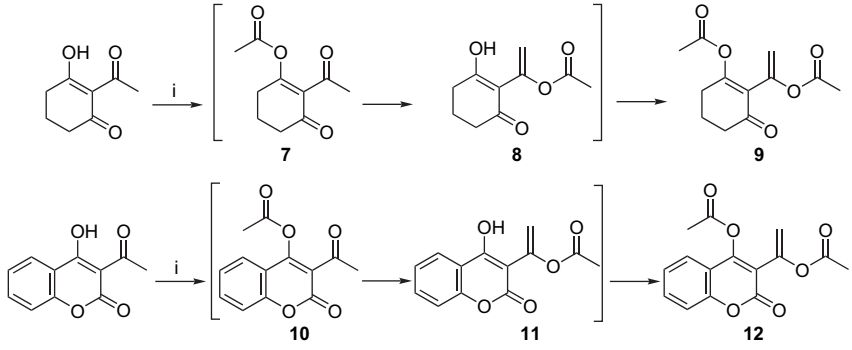


Scheme 5. The acidichromic switch of **5** and the corresponding colors in acidic, neutral, and basic conditions.

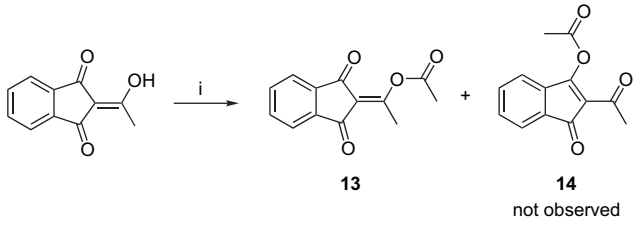


Scheme 6. Three possible tautomers of 2-acetyl-1,3-indandione.

Similar to the acylation reaction, alkylation of 2-acetyl-1,3-cyclohexanedione and 3-acyl-4-hydroxycoumarin has been found to occur specifically at endocyclic enolic oxygen to give the corresponding enol ether, whereas alkylation of 2-acyl-1,3-indandione occurred specifically at exocyclic enolic oxygen. Interestingly, reactions of 3-acetyl-4-hydroxy-7-*N*,*N*-dimethylaminocoumarin with excess diazomethane in methylene chloride generated the expected methylated compound **15** along with a minor ring cyclization

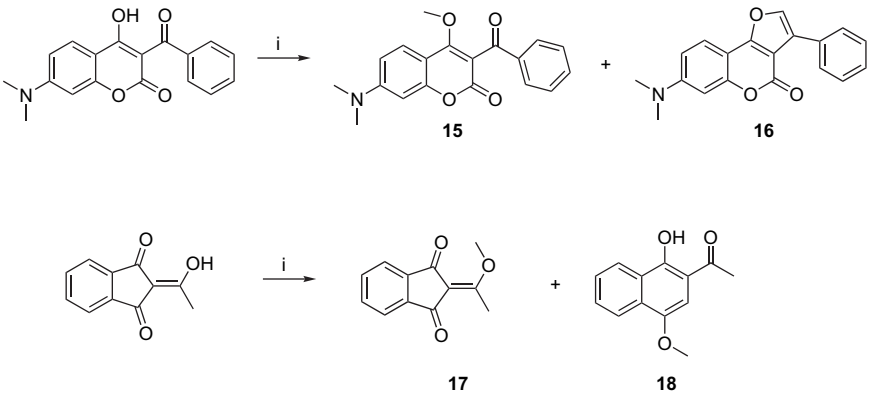


Scheme 7. Acetylation and subsequent 1,5-acyl transfer reaction of 2-acetyl-1,3-cyclohexanedione and 3-acetyl-4-hydroxycoumarin. Reagents and conditions: (i) acetyl chloride, Et_3N, CH_2Cl_2, rt.



Scheme 8. Acetylation of 2-acetyl-1,3-indandione. Reagents and conditions: (i) acetyl chloride, Et_3N, CH_2Cl_2, rt.

product **16**. Reaction of 2-acetyl-1,3-indandione with excess diazomethane under the same conditions, on the other hand, gave the ring expansion product **18**, in addition to methyl enol ether **17** (Scheme 9). Although these methylation and ring expansion reactions have been described in the literature a quarter of a century ago,[13] the X-ray structure of **17** was not provided. Thus, the real structure of **17** remains unclear. Here we present the crystal structures of **16**, **17**, and **18**, as shown in Figure 3.[14] The X-ray structure of **17** confirmed unambiguously that the methylation of 2-acyl-1,3-indandione did occur



Scheme 9. Methylation products of two triketone derivatives with excess diazomethane. Reagents and conditions: (i) CH_2N_2, CH_2Cl_2, 0 °C.

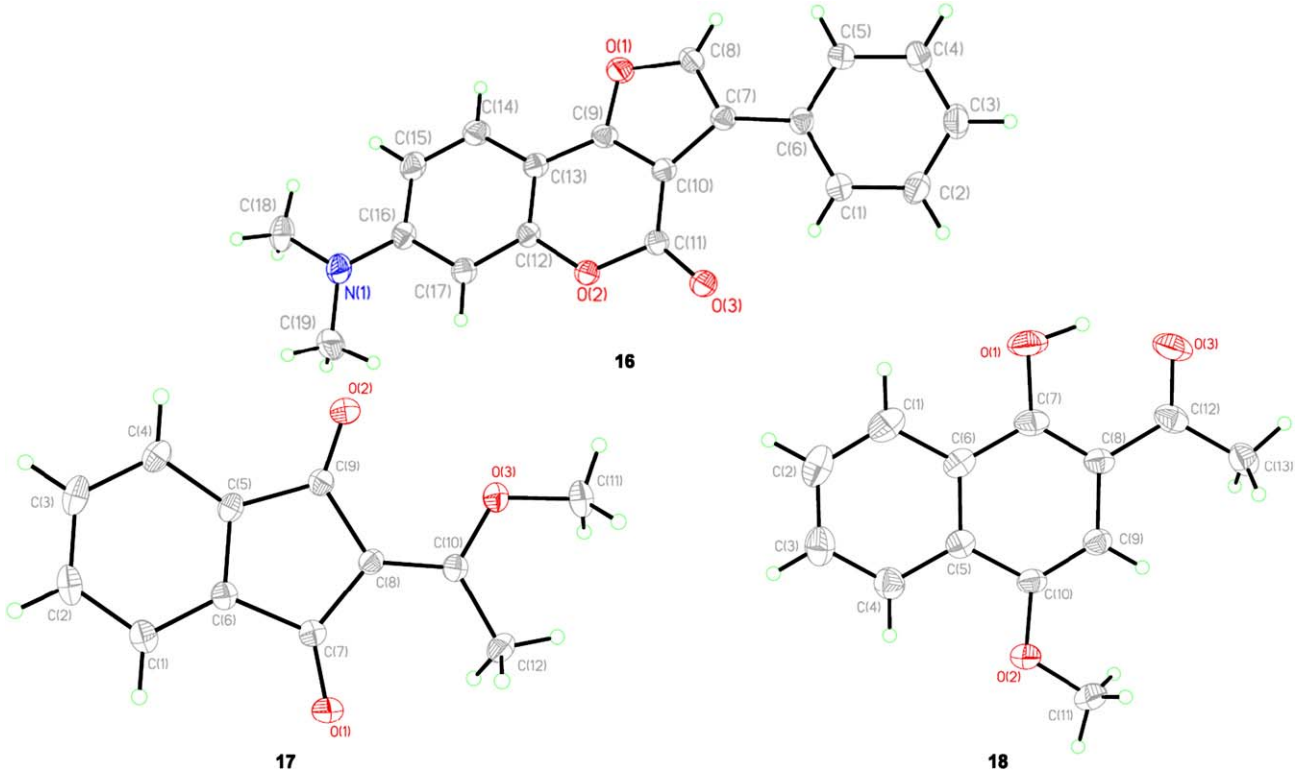


Figure 3. X-ray crystal structures of compounds **16**, **17**, and **18**.

at exocyclic enolic oxygen instead of the previously reported endocyclic enolic one. The favored stabilization energy gained after aromatization seems to be the major driving force for the formation of cyclization product **16** and ring expansion product **18**.

3. Conclusions

The solvent-sensitive property of the triketones has been successfully applied in the design and synthesis of a polarity-sensitive fluorescent probe. Additionally, we have demonstrated that the major tautomer of the triketone derivatives in organic solvents can be easily switched from endocyclic enol form to the exocyclic enol one by a simple conjugation extension. The resulting conjugated system, together with its base-sensitive property, has been applied to develop an acidichromic colorant. Moreover, acylation of 2-acyl-1,3-dimedone and 2-acyl-4-hydroxycoumarin was found to occur specifically at endocyclic enolic oxygen followed by a subsequent 1,5-acyl transfer reaction, while acylation of 2-acyl-1,3-indandione occurred at exocyclic enolic oxygen to give the corresponding enol ester without further rearrangement. Similarly, alkylation of 2-acetyl-1,3-cyclohexanedione and 3-acyl-4-hydroxycoumarin has been found to occur specifically at endocyclic enolic oxygen, whereas alkylation of 2-acyl-1,3-indandione occurred at exocyclic enolic oxygen. Finally, the structures of cyclization and ring expansion products of methylation of 3-acetyl-4-hydroxy-7-*N*,*N*-dimethylaminocoumarin and 2-acetyl-1,3-indandione, respectively, with excess diazomethane have also been characterized by X-ray crystallography.

4. Experimental

4.1. General

Melting points were determined on a Mel-Temp melting point apparatus in open capillaries and are uncorrected. ^{1}H and ^{13}C NMR spectra were recorded at 300 and 75 MHz on a Varian VXR300 spectrometer. Chemical shifts were reported in parts per million on the δ scale relative to an internal standard (tetramethylsilane or appropriate solvent peaks) with coupling constants given in hertz. ^{1}H NMR multiplicity data are denoted by s (singlet), d (doublet), t (triplet), q (quartet), and m (multiplet). Analytical thin-layer chromatography (TLC) was carried out on Merck silica gel 60G-254 plates (25 mm) and developed with the solvents mentioned. Flash chromatography was performed in columns of various diameters with Merck silica gel (230–400 mesh ASTM 9385 kieselgel 60H) by elution with the solvent systems. Solvents, unless otherwise specified, were of reagent grade and distilled once prior to use. All new compounds exhibited satisfactory spectroscopic and analytical data. Preparation of compounds **5** and **6** has been previously reported.[6]

4.2. UV and fluorescence measurements

Absorption spectra were acquired using an HP8453 spectrophotometer and emission spectra were obtained on a Hitachi F-4500 fluorospectrometer.

4.3. Calculation of fluorescence quantum yield

UV–vis spectra were measured on an HP8453 spectrometer with a 1 cm path length quartz cell. Fluorescence spectra were measured on a Hitachi F-4500 fluorescence spectrophotometer. Coumarin 1 (Φ_f=0.99, λ_{max}=374 nm in CH_2Cl_2) was used as an external standard for the measurement of fluorescence quantum yields of **4**. Fluorescence quantum yields were measured by comparing the integrated area under the fluorescence curve for the compound **4** and coumarin 1 at equal absorbance at the same excitation wavelength. The quantum yields were corrected for the refractive index of the solvent.

4.3.1. 7-(*N*,*N*-Dimethylamino)-4-hydroxycoumarin (2). To a solution of compound **1** (0.1 g, 0.5 mmol) in toluene (20 mL) was added 3-*N*,*N*-dimethylaminophenol (0.4 g, 0.5 mmol). The reaction mixture was refluxed for 7 h. After completion of the reaction, the cake was filtered and washed with hexanes. The crude product was dried under vacuum to give a gray solid in an 85% yield. Mp 261–262 °C (lit.[7] 260–262 °C). ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.55 (d, J=8.7 Hz, 1H), 6.68 (dd, J=8.7, 2.4 Hz, 1H), 6.48 (d, J=2.4 Hz, 1H), 5.27 (s, 1H), 2.99 (s, 6H).

4.3.2. 7-(*N*,*N*-Dimethylamino)-2-oxo-2*H*-chromen-4-yl acetate (3). To a stirred mixture of 7-*N*,*N*-dimethylamino-4-hydroxycoumarin **2** (1.0 g, 4.9 mmol) and triethylamine (0.5 g, 4.9 mmol) in methylene chloride (20 mL) was added acetyl chloride (0.4 g, 4.9 mmol) at 0 °C for 30 min. After completion of the reaction, 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 = 1:9) to give a brown solid in a 95% yield. Mp 110–111 °C. ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.35 (d, J=9.0 Hz, 1H), 6.57 (dd, J=9.0, 2.4 Hz, 1H), 6.43 (d, J=2.4 Hz, 1H), 6.08 (s, 1H), 3.03 (s, 6H), 2.40 (s, 3H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ 166.6, 162.6, 159.4, 155.7, 153.3, 123.2, 108.8, 103.9, 99.0, 97.6, 77.4, 77.0, 76.6, 40.0, 21.1. HRMS (EI) *m*/*z* calcd for $C_{13}H_{13}NO_4$ 247.0846, found 247.0845 (M^+). IR ν (KBr) 3346, 1608, 893, 796 cm^{-1}.

4.3.3. 3-Acetyl-7-(dimethylamino)-4-hydroxy-2*H*-chromen-2-one (4). To a solution of compound **3** (3.2 g, 12.9 mmol) in methylene chloride (20 mL) were added KCN (1.6 g, 24.6 mmol) and a catalytic amount of 18-crown-6 at room temperature for three days. After completion of the reaction, 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 = 1:6) to give a red solid in an 85% yield. Mp 169–170 °C. ^{1}H NMR ($CDCl_3$, 300 MHz) δ 17.64 (s, 1H), 7.82 (d, J=9.3 Hz, 1H), 6.63 (dd, J=9.3, 2.4 Hz, 1H), 6.37 (d, J=2.4 Hz, 1H), 3.12 (s, 6H), 2.72 (s, 3H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ 204.4, 177.9, 161.1, 157.0, 155.7, 126.7, 109.2, 103.2, 98.6, 96.8, 77.4, 77.0, 76.6, 40.1, 29.8. HRMS (EI) *m*/*z* calcd for $C_{13}H_{13}NO_4$ 247.0845, found 247.0853 (M^+). IR ν (KBr) 3406, 1726, 1619, 1423, 823, 768 cm^{-1}.

4.3.4. 2-(1-Acetoxyethylidene)-1,3-indandione (13). To a solution of 2-acyl-1,3-indandiones (500 mg, 2.66 mmol) and triethylamine (200 mg, 2.66 mmol) in dichloromethane (5 mL) was added acetyl chloride (270 mg, 2.66 mmol) at room temperature for 1 h. After completion of the reaction, 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 = 1:9) to give a yellow solid in a 90% yield. Mp 94–95 °C (lit.[15] 93–95 °C). ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.95–7.94 (m, 1H), 7.89–7.88 (m, 1H), 7.79–7.76 (m, 2H), 2.63 (s, 3H), 2.41 (s, 3H).

4.4. General procedure for preparation of compounds 9 and 12

To a solution of 2-acetyl-3-hydroxycyclohex-2-enone (0.1 g, 0.65 mmol) and triethylamine (0.2 g, 1.75 mmol) in methylene chloride (5 mL) was added acetyl chloride (0.1 g, 1.62 mmol) at room temperature for three days. After completion of the reaction, 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 to give the desired product.

4.4.1. Acetic acid 2-(1-acetoxyvinyl)-3-oxo-cyclohex-1-enyl ester (9). Brown liquid. Yield 95%. ^{1}H NMR

($CDCl_3$, 300 MHz) δ 5.20 (d, J=1.8 Hz, 1H), 4.94 (d, J=1.8 Hz, 1H), 2.64 (t, J=6.3 Hz, 2H), 2.50 (t, J=6.3 Hz, 2H), 2.22 (s, 3H), 2.08 (s, 3H), 2.05 (quintet, J=6.3 Hz, 2H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ 196.0, 168.4, 167.6, 167.0, 143.8, 125.4, 108.4, 37.1, 28.9, 20.8, 20.8, 20.2. HRMS (EI) *m/z* calcd for $C_{12}H_{14}O_5$ 238.0841, found 238.0849 (M^+). IR ν (KBr) 1763, 1685, 1368, 1204, 1011, 889 cm^{-1}.

4.4.2. Acetic acid 1-(4-hydroxy-2-oxo-2*H*-1-benzopyran-3-yl)vinyl ester (12). White solid. Yield 88%. Mp 109–110 °C. ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.59 (ddd, J=8.4, 6.9, 1.5 Hz, 1H), 7.48 (dd, J=7.8, 1.2 Hz, 1H), 7.36–7.28 (m, 2H), 5.42 (d, J=4.8 Hz, 1H), 5.41 (d, J=4.8 Hz, 1H), 2.45 (s, 3H), 2.16 (s, 3H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ 168.2, 166.6, 159.3, 156.0, 152.5, 143.1, 133.0, 124.5, 123.4, 116.7, 115.6, 114.6, 110.6, 20.6. HRMS (EI) *m/z* calcd for $C_{15}H_{12}O_6$ 288.0634, found 288.0640 (M^+). IR ν (KBr) 1757, 1612, 1363, 1194, 1084, 765 cm^{-1}.

4.5. General procedure for preparation of compounds 15–18

To a solution of 2-acetyl-1,3-indandione (0.5 g, 2.7 mmol) in dichloromethane (5 mL) was added excess diazomethane at 0 °C. After completion of the reaction (monitored by TLC), the solvent was concentrated in vacuo. The crude product was purified by column chromatography to give the desired product.

4.5.1. 3-Benzoyl-7-dimethylamino-4-methoxy-4a,8a-dihydro-1-benzopyran-2-one (15). Yellow solid. Yield 75%. Mp 132–133 °C. ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.99 (d, J=8.1 Hz, 2H), 7.63 (d, J=9.0 Hz, 1H), 7.60–7.40 (m, 3H), 6.58 (dd, J=9.0, 2.1 Hz, 1H), 6.39 (s, 1H), 3.81 (s, 3H), 2.99 (s, 6H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ 193.0, 165.0, 154.5, 153.2, 137.4, 133.2, 129.1, 128.3, 124.6, 108.7, 104.1, 96.6, 60.2, 39.6. HRMS (EI) *m/z* calcd for $C_{19}H_{17}NO_4$ 323.1158, found 323.1163 (M^+). IR ν (KBr) 1617, 1583, 1250, 833, 766 cm^{-1}.

4.5.2. 7-Dimethylamino-3-phenyl-5a,9a-dihydrofuro[3,2-*c*][1]benzopyran-4-one (16). Yellow solid. Yield 8%. Mp 187–188 °C. ^{1}H NMR ($CDCl_3$, 300 MHz) δ 6.68 (dd, J=7.2, 1.5 Hz, 2H), 7.68 (d, J=8.7 Hz, 1H), 7.61 (s, 1H), 7.46–7.36 (m, 3H), 6.68 (dd, J=9.0, 2.4 Hz, 1H), 6.62 (d, J=2.4 Hz, 1H), 3.05 (s, 6H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ 160.4, 158.6, 154.8, 152.3, 139.4, 129.6, 128.5, 128.4, 127.9, 126.2, 121.6, 109.2, 104.2, 101.7, 98.3, 40.2. HRMS (EI) *m/z* calcd for $C_{19}H_{15}NO_3$ 305.1052, found 305.1047 (M^+). IR ν (KBr) 1711, 1376, 1113, 815, 755 cm^{-1}.

4.5.3. 2-(1-Methoxyethylidene)-1,3-indandione (17). White solid. Yield 15%. Mp 161–163 °C (lit.[13] 163–165 °C). ^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.83–7.79 (m, 2H), 7.67–7.64 (m, 2H), 4.08 (s, 3H), 2.76 (s, 3H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ 191.0, 188.6, 179.0, 140.3, 139.4, 133.8, 133.5, 121.9, 121.8, 111.2, 56.2, 14.5.

4.5.4. 1-(1-Hydroxy-4-methoxynaphthalen-2-yl)ethanone (18). Yellow solid. Yield 40%. Mp 116–117 °C (lit.,[13] 118–120 °C). ^{1}H NMR ($CDCl_3$, 300 MHz) δ 13.75 (s, 1H), 8.45 (d, J=8.3 Hz, 1H), 8.19 (d, J=8.3 Hz, 1H), 7.69–7.55 (m, 2H), 6.80 (s, 1H), 3.97 (s, 3H), 2.67 (s, 3H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ 203.7, 157.4, 147.4, 130.3, 129.7, 126.6, 125.9, 124.4, 121.9, 112.0, 100.9, 55.7, 27.0.

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