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# Molecular iodine: A versatile catalyst for the synthesis of bis(4-hydroxycoumarin) methanes in water

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**Abstract**

Molecular iodine has been used an efficient catalyst for an improved and rapid one-pot synthesis of 3,3′-arylmethylenebis-(4-hydroxycoumarin) and 2,2′-arylmethylenebis(3-hydroxyl-5,5-dimethyl-2-cyclohexen-1-one) in excellent yields using water as a reaction medium. This aqua mediated Michael addition of various aromatic and heteroaromatic aldehydes with 4-hydroxycoumarin or dimedone using catalytic amount of molecular iodine devoids the use of expensive, corrosive reagents, toxic sovents and provides the operational simplicity.


*Keywords:* 3,3′-Arylmethylenebis-(4-hydroxycoumarin); 2,2′-Arylmethylenebis(3-hydroxyl-5,5-dimethyl-2-cyclohexen-1-one); Michael condensation; Water; Molecular iodine

Coumarins are an important group of organic compounds that are used as additives to food, cosmetic [1] and optical brightening agent [2]. Along with these, coumarin derivatives have recently revealed new biological activities with interesting potential in therapeutic application besides their traditional employment as anticoagulant (antivitamin K activity) [3] and sustaining agents (photosensitizing action of furocoumarin) [4], they have yielded important results as an antibiotics (novobiocin and analogs) [5] and antitumor drug (geiparvarin) [6].

The concept of "Green Chemistry" [7] has been widely adopted to meet the fundamental scientific challenges of protecting human health and environment while simultaneously achieving the commercial viability. One of thrust area for achieving this target is to explore alternative reaction conditions and reaction media to a accomplish the desired chemical transformation with minimum by products and waste generation as well as eliminating the use of volatile and toxic organic solvents [8]. It is therefore of utmost important to evolve simple and effective methodology for the synthesis of coumarin and its derivatives that cover the concept of "Green Chemistry". The uses of environmentally benign solvents like water represent green solvent, being economical and eco-friendly for synthetic transformations [9,10]. However low solubility of reactant, incompatibility of certain intermediate or competition between the desired reaction and hydrolysis restrict the use of $H_2O$ as a common solvent, although many reactions have been studied in $H_2O$ using different catalyst [11].

Knoevenagel condensation [12] is a common method for forming olefinic carbon–carbon bond in organic synthesis. In general several strategies [10,13] have been developed to carry out classical Knoevenagel condensation between carbonyl compound and active methylene carbon in the presence of bases such as ethylenediammine, piperidene or corresponding ammonium salts [14], amino acids [15], and potassium fluoride mixture [16]. There are a few number of Lewis acid catalyst [17] known to promote this reaction. However, the harsh reaction conditions, longer reaction times, alternative energy source like ultrasonic [18], microwave [10] and usage of corrosive reagents is not desirable for industrial purposes. Therefore it was thought worthwhile to develop a new and mild methodology that overcomes the drawbacks of classical catalysis.

Over past few years, molecular iodine has emerged as powerful catalyst in various organic transformation [19]. Owing to several advantages such as inexpensive, non-toxic and nature

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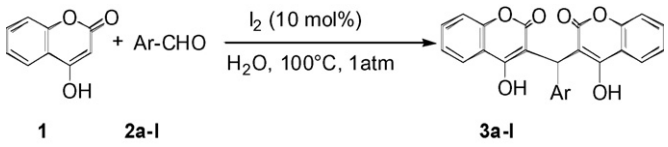



Scheme 1. Iodine catalysed aqua mediated synthesis of Michael adduct.

friendly, iodine affords the desired product in good to excellent range yields with high selectivity. Molecular iodine behaves as a mild Lewis acid [20] that encourages its role in organic synthesis for other organic transformations through its usage from stoichiometric level to catalytic amount. The present work shows that molecular iodine proves as an excellent catalyst in aqueous reaction medium.

In our continued interest towards Green Chemistry [21], coupled with the benefits of using molecular iodine [22] as a catalyst and development of new synthetic methodology [23], we report here in a very simple and highly efficient molecular iodine catalysed synthesis of Michael adduct 3,3′-arylmethylenebis-(4-hydroxycoumarin) in aqueous heterogenous system.

Benzaldehyde was choosen as representative aromatic aldehyde to optimize parameters. We tried to investigate the catalytic property of molecular iodine for Knoevenagel condensation of 4-hydroxycoumarin but to our surprise Michael product was obtained. Thus it is elucidated that 4-hydroxycoumarin is not a Knoevenagel reagent but it react further to electron poor alkenes, i.e. benzylidene which is formed by nucleophilic addition of 4-hydroxycoumarin to the benzaldehyde followed by dehydration, in the Michael addition fashion to give 3,3′-phenylmethylenebis-(4-hydroxycoumarin). The desired product were obtained in 97% yield on treating 2 mmol of 4-hydroxycoumarin with 1 mmol of benzaldehyde using 10 mol% of molecular iodine in water under reflux for 25 min (Scheme 1). The compound **3a** characterized by spectral analysis including single crystal X-ray crystallography [24] (Figs. 1 and 2).

With these optimistic results in hand, further investigations were carried out for catalytic evaluation of iodine for best reaction conditions. The increase in the amount of iodine up to

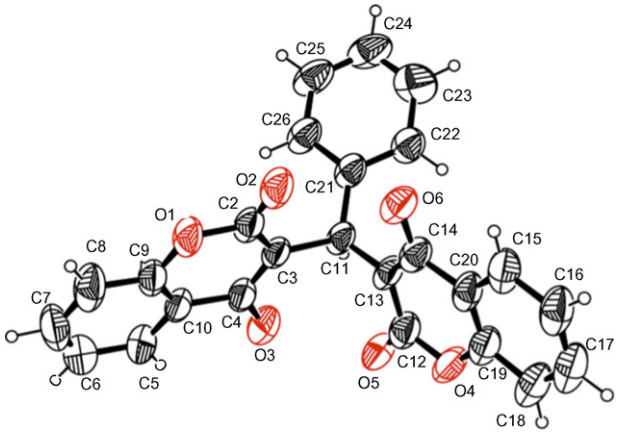



Fig. 1. ORTEP view of the compound **3a** at 50% ellipsoidal probability. Crystallographic data for the structure **3a** have been deposited within the Cambridge crystallographic data center as supplementary publication number CCDC 604526.

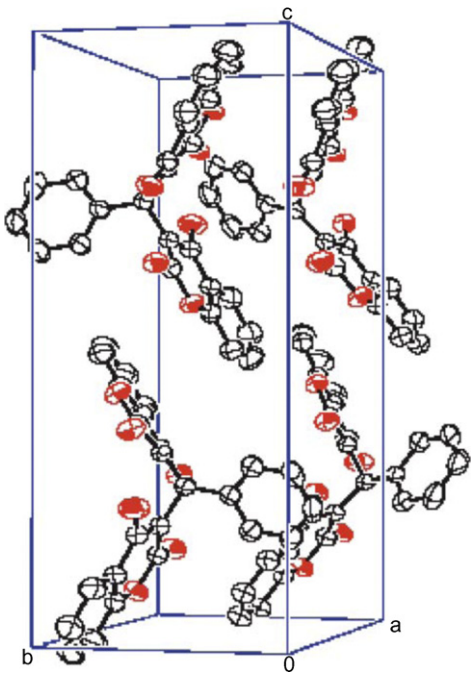



Fig. 2. The packing of compound 3,3′-benzylidenedi-4-hydroxycoumarin (**3a**).

50 mol% not only enhances the product yield but also lessens the reaction time as depicted in Table 1. The results clearly indicate that even 5 mol% of iodine is sufficient to catalyze the reaction. However in the absence of iodine reaction yield only 14% of **3a** even after reflux for 8 h.

Based on above observations a range of aromatic and heteroaromatic aldehydes were subjected to react with 4-hydroxycoumarin in the presence of 10 mol% of iodine and water as solvent in lieu of organic solvents to afford desired product **3a–l** (Table 2). It was found that both aromatic and heteroaromatic aldehydes reacted equally good to give the products in excellent yields. Different subsituted aryl group (both electron donating and electron withdrawing) has not shown much effect on the formation of final product.

Encouraged by these results, we tried to extend the scope of this process to another active methylene compound dimedone, which is an important synthon for the synthesis of various heterocyclic compounds (Scheme 2) (Table 3). As expected desired Michael adducts were obtained in an excellent yields in less reaction times.

Table 1
Catalytic activity evaluation for Michael adduct[a]

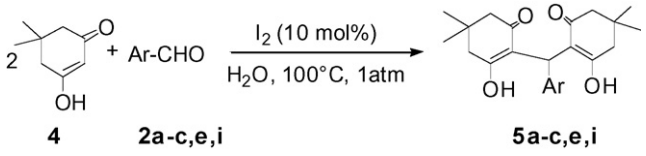
| Entry | Iodine (*x* mol%)[a] | Time (min) | Yield (%)[b] |
|---|---|---|---|
| 1 | 0 | 8(h) | 14 |
| 2 | 10 | 25 | 97 |
| 3 | 20 | 20 | 97 |
| 4 | 30 | 16 | 98 |
| 5 | 45 | 15 | 99 |
| 6 | 50 | 10 | 99 |

[a] Reaction conditions: benzaldehyde (1mmol); 4-hydroxycoumarin (2 mmol); solvent $H_2O$; 100 °C, 1 atm.
[b] Isolated yields.

Table 2
Iodine catalysed Michael adduct[a]

| Entry | 2 | Ar | Time | Product | Yield (%)[b] |
|---|---|---|---|---|---|
| 1 | **2a** | $-C_6H_5$ | 25 | **3a** | 97 |
| 2 | **2b** | 4-$ClC_6H_4$ | 27 | **3b** | 93 |
| 3 | **2c** | 4-$NO_2C_6H_4$ | 28 | **3c** | 95 |
| 4 | **2d** | 3-$NO_2C_6H_4$ | 26 | **3d** | 94 |
| 5 | **2e** | 4-$HOC_6H_4$ | 24 | **3e** | 98 |
| 6 | **2f** | 2-$HOC_6H_4$ | 20 | **3f** | 98 |
| 7 | **2g** | 4-$MeOC_6H_4$ | 28 | **3g** | 99 |
| 8 | **2h** | $-CH{=}CH-C_6H_4$ | 34 | **3h** | 92 |
| 9 | **2i** | 3,4-Piperonyl | 23 | **3i** | 96 |
| 10 | **2j** | 3-Indolyl | 28 | **3j** | 95 |
| 11 | **2k** | 2-Thiophenyl | 32 | **3k** | 91 |
| 12 | **2l** | 2-Furanyl | 26 | **3l** | 93 |

[a] Reaction conditions: aromatic/heteroaromatic aldehyde (1 mmol); 4-hydroxycoumarin (2 mmol); $I_2$ (10 mol%); solvent $H_2O$; 100 °C, 1 atm.
[b] Isolated yields.




Scheme 2. Iodine catalysed "2,2′-arylmethylenebis(3-hydroxyl-5,5-dimethyl-2-cyclohexen-1-one)".

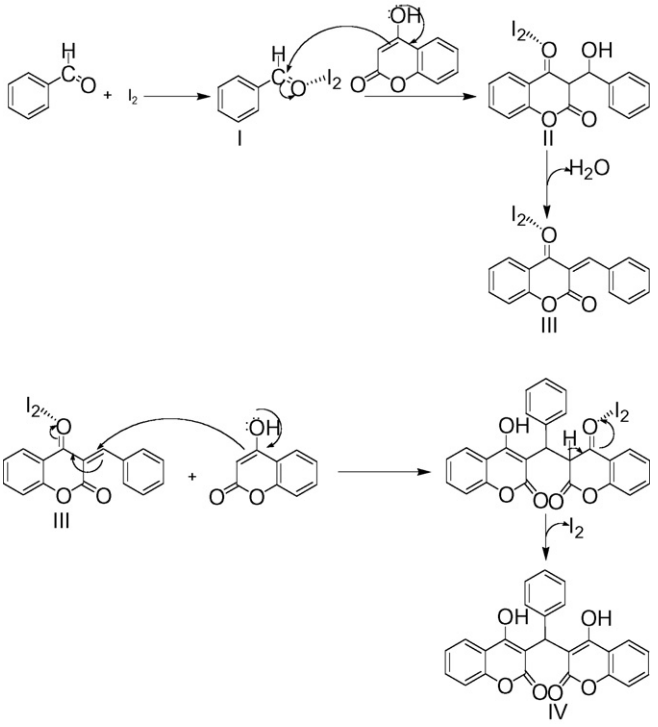



Fig. 3. Plausible mechanism for the catalytic activity of molecular iodine.

Molecular iodine is capable of binding with the carbonyl oxygen increasing the reactivities of parent carbonyl as it behaves as a mild Lewis acid. As shown in Fig. 3, first molecular iodine activates carbonyl group of aromatic aldehyde to give iodine-aldehyde complex **I** and thus increases the electrophilicity carbonyl carbon of aldehyde. Nuleophilic addition of 4-hydroxycoumarin to **I** to give **II** and followed by loss of $H_2O$ from **II** to afford **III**, which is further activated by iodine. Another molecule of 4-hydroxycoumarin is added to **III** to give **IV** and molecular iodine, which can catalyze reaction in a catalytic manner.

In conclusion we have successfully demonstrated a simple and efficient methodology to prepare a variety of Michael adduct. Iodine shows a very strong catalytic activity in aqueous medium, which is much faster then any catalyst reported so far for the synthesis of 3,3′-arylmethylenebis-(4-hydroxycoumarin) in water. The powerful catalytic activity of the iodine transformation can be substantiated by less reaction time as well as high product yields. This is an environmentally benign process for the generation of Michael adducts.

Table 3
Iodine catalysed Michael adduct[a] "2,2′-arylmethylenebis(3-hydroxyl-5,5-dimethyl-2-cyclohexen-1-one)"

| Entry | 2 | Ar | Time (min) | Product | Yield (%)[b] |
|---|---|---|---|---|---|
| 1 | **2a** | $-C_6H_5$ | 20 | **8a** | 96 |
| 2 | **2b** | 4-$ClC_6H_4$ | 30 | **8b** | 93 |
| 3 | **2c** | 4-$NO_2C_6H_4$ | 27 | **8c** | 89 |
| 4 | **2e** | 4-$HOC_6H_4$ | 23 | **8e** | 97 |
| 5 | **2i** | 3,4-Piperonyl | 25 | **8i** | 95 |

[a] Reaction conditions: aromatic/heteroaromatic aldehyde (1 mmol); dimedone (2mmol); $I_2$ (10 mol%); solvent $H_2O$; 100 °C, 1 atm.
[b] Isolated yields.

## 1. Experimental

### 1.1. General

Melting points were determined using a Thomas Hoover melting point apparatus and are uncorrected. IR spectra were recorded on Perkin-Elmer FT-IR-1710 spectrophotometer using Nujol film. $^1H$ NMR and $^{13}C$ NMR spectra were recorded on a Bruker Avance Spectrospin 300 at 300 and 75 MHz, respectively using TMS as internal standard and chemical shift are in $\delta$. Analytical TLC's were performed on pre-coated Merck silica gel 60 $F_{254}$ plates using 20% ethylacetate in *n*-hexane as eluantand; the spots were detected either under UV light or by placing in iodine chamber. Elemental analysis was performed on a Horeaus CHN Rapid analyzer. Mass spectra were recorded on a Waters LCT Micromass. X-ray diffraction data were collected on Enraf–Nonius CAD4 Diffractometer. The temperature of the reaction mixture was measured through a non-contact infrared thermometer (AZ, Mini Gun type, model 8868). The isolated product **4a–l** and **9a–c**, **e**, **i** were further purified by column chromatography using silica gel (Aldrich 24, 217-9, 70 35-70, mesh 40 Å, surface area 675 $m^2/g$) and purified products were recrystallized.

### 1.2. X-ray crystallography

The compound was crystallized from its solution in chloroform:ethanol (6:4). The unit cell parameters were refined by

the least-squares fit of 25 high angle ($25^\circ \leq \theta \leq 40^\circ$) reflections. These reflections were centred individually on the diffractometer. The Lorentz and polarisation corrections were applied. The absorption correction was not applied due to small size of the crystals (0.2 mm × 0.4 mm × 0.2 mm). The structure was determined with direct methods using the program SHELXS 97 [25]. The coordinates of non-hydrogen atoms were refined anisotropically using program SHELXL 97 [26]. The positions of hydrogen atoms were obtained from difference Fourier maps and were included in the final cycles of refinement using isotropic temperature factors of non-hydrogen atoms to which they were attached. The final *R*-factor for 3767 observed reflections [$I \geq 2\sigma(I)$] was 0.067. The atomic scattering factors used in these calculations were those of Cromer and Mann [27] for non-hydrogen atoms and Stewart, Davidson and Simpson [28] for hydrogen atoms.

### *1.3. Synthesis*

#### *1.3.1. General Procedure for the synthesis of 3,3′-arylmethylenebis-(4-hydroxycoumarin) (**3a–l**) and 2,2′-arylmethylenebis(3-hydroxyl-5,5-dimethyl-2-cyclohexen-1-one) (**5a–c, e, i**)*

A mixture of 4-hydroxycoumarin **1** (20 mmol)/3-hydroxy-5,5-dimethyl-cyclohex-2-enone **8** (20 mmol), aromatic and heteroaromatic aldehydes **2a–l** (10 mmol) and iodine (10 mol%) in 30 ml of water was stirred at 100 °C for the appropriate time mentioned in Tables 2 and 3. The completion of reaction was monitored by TLC. After completion of reaction, the reaction mixture was diluted with water (having small amount of $Na_2S_2O_3$). The solid crude products, which separated out, were filtered, washed with water and dried. The isolated products which were single spot on TLC (silica gel coated aluminium plates, Merk) were subjected to further purification by column chromatography using silica gel with 25% ethylacetate in petroleum ether as eluent to yield 3,3′-arylmethylenebis-(4-hydroxycoumarin) **3a–l**/2,2′-arylmethylenebis(3-hydroxyl-5,5-dimethyl-2-cyclohexen-1-one) **5a–c**, **e**, **i**, respectively.

### *1.4. Spectral analysis of compounds **3a–l** and **5a–c, e, i***

#### *1.4.1. Compound **3a***

White crystalline solid; mp 228–230 °C (from $CHCl_3$:EtOH) (6:4); IR ($cm^{-1}$, Nujol): 3035, 1660, 1604 and 761; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 6.2 (1H, s, CH) and 7.1–8.3 (13H, m, 13 × CH); $^{13}C$ NMR ($CDCl_3$; $Me_4Si$; 75 MHz): $\delta$ 16.25, 91.23, 104.51, 107.093, 116.32, 117.91, 123.50, 124.22, 126.12, 126.94, 128.50, 129.723, 132.45, 139.63, 163.35 and 165.44; $C_{25}H_{16}O_6$ (411.78): calcd. C, 72.81; H, 3.91. Found: C, 72.69; H, 3.83.

#### *1.4.2. Compound **3b***

White crystalline solid; mp 252–254 °C (from EtOAc:EtOH) (5:5); IR ($cm^{-1}$, Nujol): 3030, 1670, 1604, 1094 and 766; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 6.1 (1H, s, CH) and 7.3–8.2 (12H, m, 12 × CH); $^{13}C$ NMR ($CDCl_3$; $Me_4Si$; 75 MHz): $\delta$ 16.48, 90.43, 105.51, 107.25, 115.28, 117.91, 123.42, 125.60,126.20, 126.94, 129.62, 130.58, 133.13, 139.63, 163.35 and 166.85; $C_{25}H_{15}ClO_6$ (445.68): calcd. C, 67.20; H, 3.38. Found: C, 67.0; H, 3.30.

#### *1.4.3. Compound **3c***

Yellow crystalline solid; mp 232–234 °C (from EtOAc: EtOH) (5:5); IR ($cm^{-1}$, Nujol): 3034, 1659, 1613, 1528, 1347and 762; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 6.6 (1H, s, CH) and 7.3–8.3 (12H, m, 12 × CH); $C_{25}H_{15}NO_8$ (458.43): calcd. C, 65.65; H, 3.31; N, 3.06. Found: C, 65.78; H, 3.34; N, 2.83.

#### *1.4.4. Compound **3d***

Yellow crystalline solid; mp 120–124 °C (from EtOAc: EtOH) (5:5); IR ($cm^{-1}$, Nujol): 3034, 1706, 1620, 1530, 1333 and 762; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 6.5 (1H, s, CH) and 7.3–8.4 (12H, m, 12 × CH); $C_{25}H_{15}NO_8$ (456.78): calcd. C, 65.65; H, 3.31; N, 3.06. Found: C, 65.69; H, 3.30; N, 3.16.

#### *1.4.5. Compound **3e***

White crystalline solid; mp 222–224 °C (from EtOAc:EtOH) (4:6); IR ($cm^{-1}$, Nujol): 3335, 3040, 1668, 1607 and 766; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 6.2 (1H, s, CH), 7.0–8.1 (12H, m, 12 × CH) and 9.8 (1H, s, OH); $C_{25}H_{16}O_7$ (429.82): calcd. C, 70.09; H, 3.76. Found: C, 70.69; H, 4.08.

#### *1.4.6. Compound **3f***

Yellow crystalline needles; mp 254–256 °C (from $CHCl_3$: EtOH) (5:5); IR ($cm^{-1}$, Nujol): 3333, 3040, 1717, 1629 and 760; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 6.4 (1H, s, CH), 7.1–8.1 (12H, m, 12 × CH) and 8.6 (1H, s, OH); $C_{25}H_{16}O_7$ (428.78): calcd. C, 70.09; H, 3.76. Found: C, 70.70; H, 3.88.

#### *1.4.7. Compound **3g***

White crystalline solid; mp 242–244 °C (from 1,4-dioxane); IR ($cm^{-1}$, Nujol): 3386, 3029, 1668, 1607, 1258, 1052 and 769; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 3.7 (3H, s, $OCH_3$), 6.4 (1H, s, CH) and 7.1–8.1 (12H, m, 12 × CH); $C_{26}H_{18}O_7$ (443.56): calcd. C, 70.58; H, 4.10. Found: C, 70.75; H, 3.96.

#### *1.4.8. Compound **3h***

Light yellow crystalline solid; mp 230–232 °C (from $CHCl_3$:EtOH) (6:4); IR ($cm^{-1}$, Nujol): 3325, 3034, 3028, 1724, 1674, 1614 and 766; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 6.5 (1H, d, CH), 6.6 (1H, d, CH=), 6.7 (1H, d, CH=) and 7.1–8.0 (12H, m, 12 × CH); $C_{27}H_{18}O_6$ (437.55): calcd. C, 73.97; H, 4.14. Found: C, 73.78; H, 4.08.

#### *1.4.9. Compound **3i***

White amorphous solid; mp 260 °C (from 1,4-dioxane); IR ($cm^{-1}$, Nujol): 3031, 1663, 1616 and 763; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 3.6 (2H, s, O–$CH_2$–O), 5.8 (1H, s, CH) and 7.6–8.5 (11H, m, 11 × CH); $^{13}C$ NMR ($CDCl_3$; $Me_4Si$; 75 MHz): $\delta$ 152.4, 147.8, 144.6, 133.7, 132.3, 124.8, 124.2, 119.7, 117.3, 115.9, 107.6, 107.6, 104.2, 100.9 and 53.8;

$C_{26}H_{16}O_8$ (455.78): calcd. C, 68.42; H, 3.53. Found: C, 68.56; H, 3.71.

*1.4.10. Compound **3j***

Orange crystalline solid; mp 240–244 °C (from EtOAc: EtOH) (6:4); IR ($cm^{-1}$, Nujol): 3307, 3070, 1632, 1587 and 747; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 12.85 (1H, s, NH), 6.6 (1H, s, CH-NH), 5.5 (1H, s, CH) and 7.2–9.1 (12H, m, 12 × CH) $C_{27}H_{17}NO_6$ (452.08): calcd. C, 71.84; H, 3.80; N, 3.10. Found: C, 71.93; H, 3.52; N, 2.98.

*1.4.11. Compound **3k***

Green crystalline solid; mp 210 dec °C (from $CHCl_3$:EtOH) (6:4); IR ($cm^{-1}$, Nujol): 3040, 1660, 1602 and 762; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 6.2 (1H, s, CH), 6.6–7.0 (3H, m, 3 × CH) and 7.3–8.0 (8H, m, 8 × CH); $C_{23}H_{14}O_6S$ (418.79): calcd. C, 66.02; H, 3.37; S, 7.66. Found: C, 66.62; H, 3.43; S, 7.34

*1.4.12. Compound **3l***

Black amorphous solid; mp 202 °C (from $CHCl_3$:EtOH) (6:4); IR ($cm^{-1}$, Nujol): 3030, 1657, 1604 and 765; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 6.0 (1H, s, CH), 6.3–6.5 (3H, m, 3 × CH) and 7.3–8.3 (8H, m, 8 × CH); $C_{23}H_{14}O_7$ (402.42): calcd. C, 68.66; H, 3.51. Found: C, 68.46; H, 3.48.

*1.4.13. Compound **5a***

White crystalline solid; mp 184–186 °C (from EtOAc); IR ($cm^{-1}$, Nujol): 3045, 1608, 1535, 1365, 1302 and 713; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 1.08 (12H, s, 4 × $CH_3$), 2.3 (8H, s, 4 × $CH_2$), 5.4 (1H, s, CH), 7.1–7.3 (5H, m, 5 × CH) and 10.8 (1H, brs, OH); $^{13}C$ NMR ($CDCl_3$; $Me_4Si$; 75 MHz): $\delta$ 190.5, 190.0, 138.3, 126.5, 124.8, 116.1, 47.4, 46.4, 32.7, 30.4, 29.8 and 26.3; $C_{23}H_{28}O_4$ (368.02): calcd. C, 74.97; H, 7.66. Found: C, 74.76; H, 7.54.

*1.4.14. Compound **5b***

White crystalline solid; mp 146–148 °C (from EtOAc); IR ($cm^{-1}$, Nujol): 3048, 1592, 1489, 1370, 1305, and 1250; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 1.1 (12H, s, 4 × $CH_3$), 2.4 (8H, s, 4 × $CH_2$), 5.4 (1H, s, CH), 7.0 (2H, d, 2 × CH), 7.1 (2H, d, 2 × CH) and 11.1 (1H, brs, OH); $^{13}C$ NMR ($CDCl_3$; $Me_4Si$; 75 MHz) $\delta$ 190.1, 189.0, 137.5, 131.4, 128.2, 126.5, 116.8, 46.3, 45.8, 32.4, 31.2, 29.5 and 27.7; $C_{23}H_{27}ClO_4$ (401.88): calcd. C, 68.56; H, 6.75. Found: C, 68.69; H, 6.83.

*1.4.15. Compound **5c***

White crystalline solid; mp 188–190 °C (from EtOAc); IR ($cm^{-1}$, Nujol): 3045, 1593, 1513, 1491, 1370 and 1345; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 1.08 (12H, s, 4 × $CH_3$), 2.4 (8H, s, 4 × $CH_2$), 5.6 (1H, s, CH), 7.2 (2H, d, 2 × CH), 7.7 (2H, d, 2 × CH) and 11.7 (1H, brs, OH); $C_{23}H_{27}NO_6$ (414.24): calcd. C, 66.81; H, 6.58; N, 3.39. Found: C, 66.70; H, 6.65; N, 3.23.

*1.4.16. Compound **5e***

White crystalline solid; mp 188–190 °C (from 1,4-dioxane); IR ($cm^{-1}$, Nujol): 3421, 3043, 1596, 1510, 1370 and 1325; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 1.2 (12H, s, 4 × $CH_3$), 2.4 (8H, s, 4 × $CH_2$), 5.3 (1H, s, CH), 6.8 (2H, d, 2 × CH), 7.0 (2H, d, 2 × CH) and 11.8 (2H, brs, 2 × OH); $C_{23}H_{28}O_5$ (383.92): calcd. C, 71.85; H, 7.34. Found: C, 72.06; H, 7.41.

*1.4.17. Compound **5i***

White crystalline solid; mp 164–166 °C (from EtOAc); $^{-1}$ 3040, 1580, 1510, 1371, and 1308; $^1H$ NMR ($CDCl_3$; $Me_4Si$; 300 MHz): $\delta$ 1.1 (12H, s, 4 × $CH_3$), 2.3 (8H, s, 4 × $CH_2$), 3.8 (2H, s, O–$CH_2$–O), 5.7 (1H, s, CH), 7.1–7.3 (3H, m, 3 × CH) and 11.6 (1H, brs, OH); $C_{24}H_{28}O_6$ (411.96): calcd. C, 69.88; H, 6.84. Found: C, 69.68; H, 6.75.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.molcata.2006.11.054.

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