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Synthesis of α- and β-Lapachone Derivatives from Hetero Diels-Alder Trapping of Alkyl and Aryl *o*-Quinone Methides

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EXPERIMENTAL

General information

Melting points were observed on a Fischer Jones and are uncorrected. Analytical grade solvents were used. Dioxane was distilled before being used. Reagents were purchased from Aldrich or Acros Chemical Co. Column chromatography was performed on silica gel 60 (Merck 70-230 mesh). Yields refer to chromatographically and spectroscopically homogeneous materials. Reactions were monitored by thin-layer chromatography (TLC) carried out on 0.25 mm E. Merck silica gel plates (60F-254) using UV light as visualizing agent and either an ethanolic solution of sulfate. Infrared spectra were recorded on a Perkin-Elmer FT-IR Spectrum One spectrophotometer, calibrated relative to the 1601.8 cm^{-1} absorbance of polystyrene. NMR spectra were recorded on a Varian Unity Plus VXR (300 MHz) equipament in DMSO-d_6 and $CDCl_3$ solutions and tetramethylsilane was used as the internal standard (δ = 0 ppm). High resolution mass spectra (HRMS) were recorded on an MICROMASS Q-TOF MICRO Mass spectrometer using ESI-TOF (electrospray ionization-time of flight).

General Procedure for preparation of 10a-f and 11a-f in dioxane media

To a round-bottom flask equipped with a magnetic stirring bar was added lawsone (1 mmol), appropriate aldehyde (8 mmols for paraformaldehyde or 3 mmols for arylaldehydes) and dissolved with dioxane (20 mL). Then substituted styrene (3 mmols) was added dropwise and reaction mixture was stirred under reflux until consumption of the starting material. The dioxane was evaporated, ethyl acetate was added and mixture was washed with saturated aqueous solution of sodium bicarbonate. The organic layer was washed with water, dried over anhydrous sodium sulphate, filtered and concentrated under reduced pressure. The residual crude product was purified via silica-gel chromatography, using gradient mixture of hexane-ethyl acetate.

General Procedure for preparation of 10a-f and 11a-f in aqueous ethanol media

To a round-bottom flask equipped with a magnetic stirring bar lawsone was dissolved (1 mmol) with water (10 mL) and ethanol (10 mL). Then, the appropriate aldehyde (8 mmols for paraformaldehyde or 3 mmols for arylaldehydes) was added. Styrenes substituted (3 mmols) was added drop-wise and reaction mixture was stirred under reflux until consumption of the starting material. The ethanol was removed under reduced pressure, ethyl acetate was added in the residue and mixture was washed with saturated aqueous solution of sodium bicarbonate. The combined organic extracts washed with water, and dried over anhydrous sodium sulphate, was filtered and concentrated under pressure reduced. The residual crude product was purified via silica-gel chromatography, using gradient mixture of hexane-ethyl acetate.

General Procedure for preparation of 10a/d and 11a/d in dioxane/acetic acid media

The general procedure was like the general procedure reported for dioxane media with additional of some drops of acetic acid.

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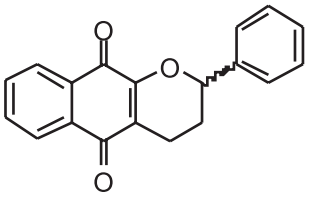
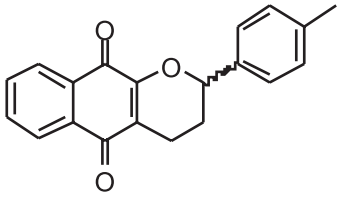
*2-phenyl-3,4-dihydro-2H-benzo[g]chromene-5,10-dione (**10a**)*



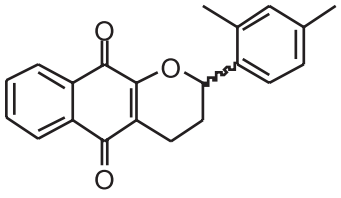
Yellow solid, m.p.= 168-170 ^{0}C; IR (KBr, cm^{-1}): ν 1679, 1649, 1617, 1260, 1202, 1063, 958, 910, 721; ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2.15 (1H, dddd, *J* = 2.6, 3.2, 5.7 and 14.0 Hz, H-3a), 2.30 (1H, dddd, *J* = 2.2, 6.2, 6.5 and 14.0 Hz, H-3b), 2.63 (1H, ddd, *J* = 3.2, 6.2 and 13.7 Hz, H-4a), 2.77 (1H, ddd, *J* = 2.2, 5.7, and 13.7 Hz, H-4b), 5.22 (1H, dd, *J* = 2,6 e 6,5 Hz, H-2), 7.32 – 7.40 (5H, m, *2-phenyl*), 7.68 (2H, dddd, *J* = 2.0, 7.5, 9.2 and 11.0 Hz, H-8 e H-7), 8.10 (2H, dddd, *J* =2.0, 7.5, 9.2 and 10.9 Hz, H-9 e H-6); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 18.3 (C-4), 27.6 (C-3), 78.8 (C-2), 121.4 (C-4a), 125.6 (C-4'-*phenyl*), 125.8 (C-6), 126.1 (C-9), 128.1 (C-2'-*phenyl*), 128.4 (C-3'-*phenyl*), 130.8 (C-9a), 131.7 (C-5a), 132.9 (C-7, C-8), 133.7 (C-Har), 139.1 (C-1'), 152.2 (C-10a), 184.0 (C-5 and C-10). HRMS (ESI) calcd for $C_{19}H_{14}O_3$: 290.0943, Found: 290.0336.

*2-(p-tolyl)-3,4-dihydro-2H-benzo[g]chromene-5,10-dione (**10b**)*



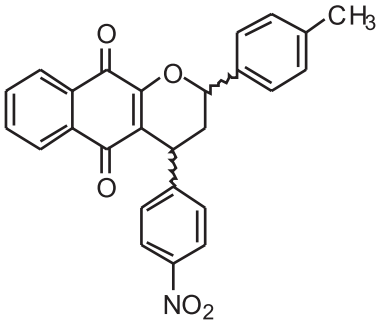
Yellow solid, m.p.= 135-137^{0}C; IR (KBr, cm^{-1}): ν 1677, 1645, 1617, 1595, 1341, 1300, 1258, 1200, 1065, 958, 910, 816, 720; ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2.06 (1H, dddd, *J* = 2.6, 3.4, 6.0 and 13.0 Hz, H-3a), 2.31 (1H, dddd, *J* = 2.3, 6.4, 6.3 and 13.0 Hz, H-3b), 2.36 (1H, s, C$\underline{H}_3$), 2,64 (1H, ddd, *J* = 3.4, 6.4 and 12.7 Hz, H-4a), 2.75 (1H, ddd, *J* = 2.3, 6.0, and 12.7 Hz, H-4b), 5.18 (1H, dd, *J* = 2.6 and 6.3 Hz, H-2), 7.1 (2H, dd, *J* = 7.7 Hz, H-*meta tolyl*), 7.27 (2H, dd, *J* = 7.7 Hz, H-*orto tolyl*), 7.69 (2H, dddd, *J* = 1.0, 7.3, 9.0 and 10.7 Hz, H-8 e H-7), 8.09 (2H, dddd, *J* = 1.0, 7.3, 9.0 and 10.7 Hz, H-9 e H-6); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 18.8 (C-4), 21.4 ($\underline{C}H_3$), 28.0 (C-3), 79.2 (C-2), 121.8 (C-4a), 126.1 (C-6), 126.2 (C-9), 126.5 (C-2'), 129.5 (C-3'), 131.3 (C-9a),133.7 (C-4'), 134.1 (C-1'), 136.3 (C-5a), 138.3 (C-1'), 155.8 (C-10a), 179.6 and 184.0 (C-5 and C-10). HRMS (ESI) calcd for $C_{20}H_{16}O_3$: 304.1099, Found: 304.1261.

*2-(2,4-dimethylphenyl)-3,4-dihydro-2H-benzo[g]chromene-5,10-dione (**10c**)*



Yellow solid, m.p.= 148-152 ^{0}C; IR (KBr, cm^{-1}): ν 1673, 1646, 1617, 1590, 1261,1204, 1299, 1063, 961, 825, 718, 676; ^{1}H NMR ($CDCl_3$, 300 MHz): δ 1.99 (1H, dddd, *J* = 2.4, 3.4, 5.9 and 13.2 Hz, H-3a), 2,25 (1H, dddd, *J* = 2.4, 6.4, 7.8 and 13.2 Hz, H-3b), 2.32 (3H, s, C$\underline{H}_3$), 2.34 (3H, s, C$\underline{H}_3$), 2.64 (1H, ddd, *J* = 3.4, 6.4 and 13.0 Hz, H-4a), 2.85 (1H, m, ddd, *J* = 2.4, 5.9, and 13.0 Hz, H-4b), 5.25 (1H, dd, *J* = 2.4 and 7.8 Hz, H-2), 7.01 (1H, s, H-*meta tolyl*), 7.06 (1H, d, *J* = 7.8 Hz, H-*orto tolyl*), 7.30 (1H, d, *J* = 7.8 Hz, H-*meta tolyl*), 7.69 (2H, dddd, *J* = 2.0, 7.8, 9.2 and 10.7 Hz, H-8 e H-7), 8.10 (2H, dddd, *J* = 2.0, 7.6, 9.2 and 10.9 Hz, H-9 e H-6); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 19.2 ($\underline{C}H_3$), 19.6 (C-4), 21.3 ($\underline{C}H_3$), 27.2 (C-3), 77.0 (C-2), 121.6 (C-4a), 125.9 (C-5' *orto tolyl)*, 126.2 and 126.5 (C-6 and C-9), 127.3 (C-6'), 131.6 (C-3' *orto tolyl)*, 131.3 (C-9a), 132.2 (C-5a), 133.3 and 134.1 (C-7 and C-8), 134.7 and 134.9 (C-2' and C-4'), 138.1 (C-1'), 156.2 (C-10a), 179.6 and 184.0 (C-5 and C-10). HRMS (ESI) calcd for $C_{21}H_{18}O_3$: 318.1256, Found: 318.1876

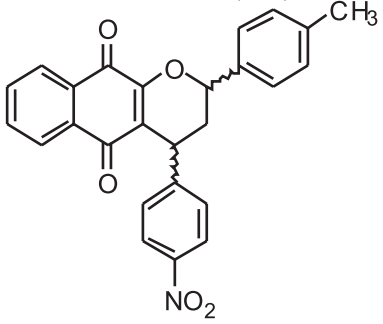
*4-(4-nitrophenyl)-2-p-tolyl-3,4-dihydro-2H-benzo[g]chromene-5,10-dione (**10d**), Syn isomer*



Yellow solid, m.p.= 205-207 ^{0}C; IR (KBr, cm^{-1}): ν 1677, 1649, 1612, 1516, 1344, 1305, 1266, 1209, 1106, 968, 900, 856, 818, 725; ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2.25 (1H, dt, *J* = 2.4 and 14.3 Hz, H-3a), 2.35 (3H, s, CH_3), 2.44 (1H, ddd, *J* = 5.7, 11.9 and 14.3 Hz, H-3b), 4.52 (1H, dd, *J* = 2.4 and 5.7 Hz, H-4), 4.99 (1H, dd, *J* = 2.4 and 11.9 Hz, H-2), 7.17 (1H, d, *J* = 8.5 Hz, H-*meta p-tolyl*), 7.22 (1H, d, *J* = 8.5 Hz, H-*ortho p-tolyl*), 7.46 (1H, d, *J* = 8.6 Hz, H-*ortho 4-nitrophenyl*), 7.71-7.77 (1H, m, H-7), 7.71-7.77 (1H, m, H-8), 8.00-8.06 (1H, m, H-9), 8.17-8.22 (1H, m,

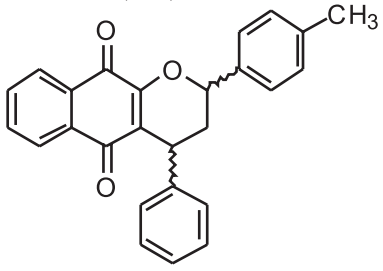
H-6), 8.22 (1H, d, *J* = 8.6 Hz, H-*meta 4-nitrophenyl*); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 21.0 (CH_3), 35.2 (C-4), 36.5 (C-3), 75.0 (C-2), 120.2 (C-4a), 124.0 (C-3' *4-nitrophenyl*), 126.0 (C-9), 126.3 (C-2' *4-nitrophenyl*), 126.5 (C-7), 128.5 (C-3' *p-tolyl*), 129.3 (C-2' *p-tolyl*), 131.0 (C-9a), 131.7 (C-5a), 133.3 (C-6), 134.2 (C-8), 135.0 (C-4' *p-tolyl*), 138.5 (C-1' *p-tolyl*), 146.8 (C-4' *4-nitrophenyl*), 151.0 (C-1' *4-nitrophenyl*), 156.6 (C-10a), 179.0 (C-10), 183.1 (C-5).

*4-(4-nitrophenyl)-2-p-tolyl-3,4-dihydro-2H-benzo[g] chromene-5,10-dione (**10d**), Anti isomer*



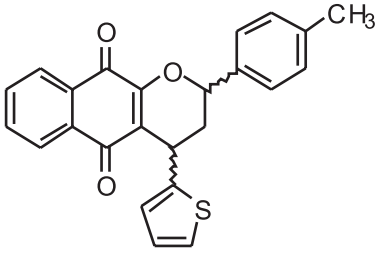
Yellow solid, m.p.= 231-234 ^{0}C; IR (KBr, cm^{-1}): ν 1677, 1650, 1607, 1511, 1345, 1301, 1266, 1258, 1199, 961, 724; ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2.25 (1H, dt, *J* = 2.4 and 14.3 Hz, H-3a), 2.35 (3H, s, CH_3), 2.62 (1H, ddd, *J* = 2.2, 7.1 and 14.4 Hz, H-3b), 4.40 (1H, dd, *J* = 7.1 and 10.7 Hz, H-4), 5.20 (1H, dd, *J* = 2.0 and 11.0 Hz, H-2), 7.18 (1H, d, *J* = 8.1 Hz, H-*meta p-tolyl*), 7.30 (1H, d, *J* = 8.1 Hz, H-*ortho p-tolyl*), 7.35 (1H, d, *J* = 8.8 Hz, H-*ortho 4-nitrophenyl*), 7.67-7.74 (1H, m, H-7), 7.67-7.74 (1H, m, H-8), 7.90-7.93 (1H, m, H-9), 8.11-8.17 (1H, m, H-6), 8.13 (1H, d, *J* = 8.8 Hz, H-*meta 4-nitrophenyl*); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 21.0 (CH_3), 29.6 (C-3), 38.6 (C-3), 79.2 (C-2), 122.8 (C-4a), 123.9 (C-3' *4-nitrophenyl*), 125.9 (C-9), 126.2 (C-2' *4-nitrophenyl*), 126.4 (C-7), 127.6 (C-3' *p-tolyl*), 129.3 (C-2' *p-tolyl*), 130.8 (C-9a), 131.8 (C-5a), 133.3 (C-6), 134.2 (C-8), 134.8 (C-4' *p-tolyl*), 138.6 (C-1' *p-tolyl*), 146.4 (C-4' *4-nitrophenyl*), 151.2 (C-1' *4-nitrophenyl*), 157.4 (C-10a), 183.2 (C-10), 186.8 (C-5).

*4-Phenyl-2-p-tolyl-3,4-dihydro-2H-benzo[g]chromene-5,10-dione (**10e**)*



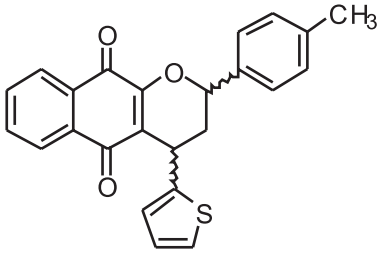
Yellow solid, m.p. = 203-205 ºC; IR (KBr/cm^{-1}): 1678, 1647, 1615, 1365, 1336, 1302, 1257, 1194, 1068, 1043, 960, 894, 812, 760, 725, 702. ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.13-2.32 (1H, m, H-3a), 2.34 and 2.35 (3H, s, CH_3), 2.44 (1H, ddd, *J* = 2.0, 7.3 and 14.4 Hz, H-3b), 4.29 (1H, dd, *J* = 7.3 and 11.0 Hz, H-4 *anti isomer*) and 4.46 (1H, dd, *J* = 1.5 and 5.7 Hz, H-4 *syn isomer*), 5.06 (1H, dd, *J* = 3.2 and 11.0 Hz, H-2 *syn isomer*) and 5.12 (1H, dd, *J* = 1.2 and 11.0 Hz, H-2 *anti isomer*), 7.14-7.34 (4H, m, *p-tolyl*), 7.14-7.34 (5H, m, Ph), 7.63-7.72 (1H, m, H-7), 7.63-7.72 (1H, m, H-8), 7.91-7.94 (1H, m, H-9 *anti isomer*) and 8.02-8.05 (1H, m, H-9 *syn isomer*), 8.11-8.18 (1H, m, H-6). ^{13}C NMR (75 MHz, $CDCl_3$): δ 21.4 (CH_3), 35.6 and 39.3 (C-4), 37.3 and 41.2 (C-3), 75.5 and 79.9 (C-2), 125.0 (C-4a), 126.5 and 126.6 (C-9), 126.7 (C-7), 126.8 (C-2' Ph), 127.1 (C-3' Ph), 128.0 (C-3' *p-tolyl*), 128.9 and 129.1 (C-4' Ph), 129.5 and 129.6 (C-2' *p-tolyl*), 131.2 (C-9a), 132.5 (C-5a), 133.3 and 133.4 (C-6), 134.3 and 134.4 (C-8), 135.8 (C-4' *p-tolyl*), 138.6 (C-1' *p-tolyl*), 143.9 (C-4' Ph), 157.5 (C-10a), 179.9 (C-10), 183.4 (C-5).

*4-(thiophen-2-yl)-2-p-tolyl-3,4-dihydro-2H-benzo[g] chromene-5,10-dione (**10f**), Syn isomer*



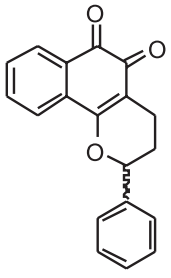
Yellow solid, m.p.= 123-125 ^{0}C; IR (KBr, cm^{-1}): ν 1680, 1650, 1614, 1338, 1299, 1261, 1205, 1063, 959, 896, 815, 721; ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2.22-2.39 (2H, m, H-3), 2.36 (3H, s, CH_3), 4.70 (1H, ddd, *J* = 0.7, 1.9 and 4.9 Hz, H-4), 5.23 (1H, dd, *J* = 2.9 and 11.2 Hz, H-2), 6.92 (1H, dt, *J* = 1.0 and 3.4 Hz, H-3' *thiophen-2-yl*), 6.96 (1H, dd, *J* = 3.7 and 5.1 Hz, H-4' *thiophen-2-yl*), 7.20 (1H, dd, *J* = 1.2 and 5.1 Hz, H-5' *thiophen-2-yl*), 7.20 (1H, d, *J* = 8.0 Hz, H-*meta*), 7.28 (1H, d, *J* = 8.0 Hz, H-*ortho*), 7.67-7.76 (1H, m, H-7), 7.67-7.76 (1H, m, H-8), 8.06-8.09 (1H, m, H-9), 8.13-8.16 (1H, m, H-6); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 21.5 (CH_3), 30.9 (C-4), 37.4 (C-3), 76.0 (C-2), 122.0 (C-4a), 124.5 (C-5' *thiophen-2-yl*), 125.5 (C-9), 126.5 (C-7), 126.7 (C-4' *thiophen-2-yl*), 127.3 (C-3' *p-tolyl*), 129.6 (C-2' *p-tolyl*), 131.4 (C-4' *p-tolyl*), 132.3 (C-6), 133.5 (C-8), 134.4 (C-3' *thiophen-2-yl*), 136.0 (C-1' *p-tolyl*), 138.6 (C-2' *thiophen-2-yl*), 147.2 (C-11), 176.5 (C-10), 183.6 (C-5).

*4-(thiophen-2-yl)-2-p-tolyl-3,4-dihydro-2H-benzo[g] chromene-5,10-dione (**10f**), Anti isomer*



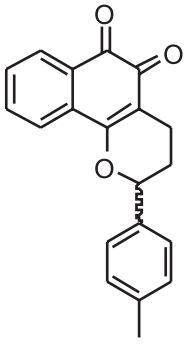
Yellow solid, m.p.= 172-175 ^{0}C; IR (KBr, cm^{-1}): ν 1678, 1649, 1611, 1363, 1333, 1300, 1256, 1192, 1041, 954, 892, 847, 814, 721; ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2.28-2.43 (1H, m, H-3a), 2.40 (3H, s, CH_3), 2.68 (1H, ddd, 2.1, 7.1 and 14.4 Hz, H-3b), 4.57 (1H, dd, *J* = 7.1 and 11.0 Hz) and 4.65 (1H, dd, *J* = 1.0 and 3.2 Hz) H-4 conformers, 5.23 (1H, dd, *J* = 1.9 and 11.5 Hz) and 5.35 (1H, dd, *J* = 4.4 and 10.0 Hz) H-2 conformers, 6.89 and 6.90 (1H, dd, *J* = 1.0 and 3.4 Hz, H-3' *thiophen-2-yl* conformers), 6.86 and 6.95 (1H, dd, *J* = 3.7 and 5.1 Hz, H-4' *thiophen-2*-y conformers), 7.06 and 7.18 (1H, dd, *J* = 1.2 and 5.1 Hz, H-5' *thiophen-2-yl* conformers), 7.24 and 7.25 (1H, d, *J* = 8.0 Hz, H-*meta* conformers), 7.30 and 7.36 (1H, d, *J* = 8.0 Hz, H-*ortho* conformers), 7.54 and 7.57 (1H, td, *J* = 1.2 and 7.6 Hz, H-8 conformers), 7.63 and 7.65 (1H, dt, *J* = 1.2 and 7.6 Hz, H-7 conformers), 7.89 (1H, d, *J* = 7.6 Hz, H-9), 8.09 and 8.13 (1H, dd, *J* = 1.5 and 7.6 Hz, H-6 conformers) ; ^{13}C NMR ($CDCl_3$, 75 MHz): δ 21.4 (CH_3), 30.9 (C-4), 41.5 (C-3), 79.9 (C-2), 124.4 (C-4a), 124.6 (C-5' *thiophen-2-yl*), 126.4 (C-9), 126.5 (C-7), 126.6 (C-4' *thiophen-2-yl*), 127.0 (C-3' *p-tolyl*), 129.6 (C-2' *p-tolyl*), 131.2 (C-4' *p-tolyl*), 132.5 (C-6), 133.4 (C-8), 134.4 (C-3' *thiophen-2-yl*), 135.5 (C-1' *p-tolyl*), 138.7 (C-2' *thiophen-2-yl*), 146.6 (C-11), 179.8 (C-10), 183.7 (C-5).

*2-phenyl-3,4-dihydro-2H-benzo[h]chromene-5,6-dione (**11a**)*



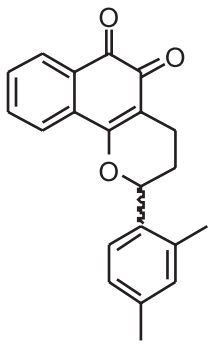
Orange solid, m.p.= 161-163 ^{0}C; IR (KBr, cm^{-1}): ν 1696, 1647, 1605,1573, 1397, 1300, 1280, 1232, 1158, 1093, 922, 700; ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2.08 (1H, dddd, *J* = 2.7, 3.2, 5.6 and 13.8 Hz, H-3a), 2.33 (1H, dddd, *J* = 3.4, 6.3, 7.4 and 13.8 Hz, H-3b), 2.60 (1H, ddd, *J* = 3.2, 6.3 and 8.8 Hz, H-4a), 2.76 (1H, ddd, *J* = 3.4, 5.6 and 8.8 Hz H-4b), 5.27 (1H, dd, *J* = 2.7 and 7.4 Hz, H-2), 7.39-7.46 (5H, m, 2-*phenyl*), 7.53 (1H, ddd, *J* = 1.2, 7.4 and 8.6 Hz,H-8), 7.64 (1H, ddd, *J* = 1.4, 7.6 and 9.1 Hz, H-9), 7.83 (1H, dd, *J* = 0.9 and 7.6 Hz, H-10), 8.01 (1H, dd, *J* = 1.4 and 7.6 Hz, H-7); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 18.2 (C-4), 28.2 (C-3), 79.9 (C-2), 113.8 (C-4a), 123.9 (C-10), 125.6 (C-7), 125.7 (C-4'-*phenyl*), 128.4 (C-8), 128.5 (C-2'-*phenyl*), 128.6 (C-3'-*phenyl*), 129.8 (C-6a), 130.6 (C-9), 131.9 (C-1'-*phenyl*), 139.2 (C-10a), 162.7 (C-10b), 178.7 and 179.0 (C-5 and C-6). HRMS (ESI) calcd for $C_{19}H_{14}O_3$: 290.0943, Found: 290.0344

*2-p-tolyl-3,4-dihydro-2H-benzo[h]chromene-5,6-dione (**11b**)*



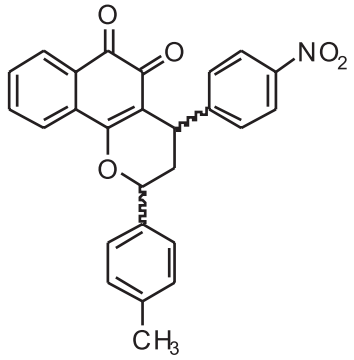
Orange solid, m.p.= 165-167 ^{0}C; IR (KBr, cm^{-1}): ν 1697, 1647, 1605, 1590, 1572, 1393, 1301, 1280, 1158, 1076, 922,771; ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2.06 (1H, dddd, *J* = 2.4, 3.6, 5.6 and 12.7 Hz, H-3a), 2.31 (1H, dddd, *J* = 3.1, 6.2, 7.8 and 12.7 Hz, H-3b), 2.40 (3H, s, C$\underline{H}_3$), 2.59 (1H, ddd, *J* = 3.6, 6.2 and 8.7 Hz, H-4a), 2.77 (1H, ddd, *J* = 3.1, 5.6 and 8.7 Hz H-4b), 5.24 (1H, dd, *J* = 2.4 and 7.8 Hz, C-2), 7.25 (2H, d, *J* = 7.7 Hz, H-*meta tolyl*), 7.32 (2H, d, *J* = 7.7 Hz, H-*orto tolyl*), 7.51 (1H, ddd, *J* = 1.4, 7.5 and 8.7 Hz, H-8), 7.62 (1H, ddd, *J* = 1.4, 7.5 and 9.0 Hz, H-9), 7.81 (1H, dd, *J* = 1.2 and 7.8 Hz, H-10), 8.01 (1H, dd, *J* = 1.4 and 7.5 Hz, H-7); ^{13}C NMR ($CDCl_3$, 75 MHz): δ18.7 (C-4), 21.4 (C$\underline{H}_3$), 28.6 (C-3), 80.4 (C-2), 114.3 (C-4a), 124.3 (C-10), 126.1 (C-7), 128.9 (C-8), 129.7 (C-2'-*phenyl*), 130.2 (C-6a), 131.0 (C-3'-*phenyl*), 132.4 (C-9'), 135.1 (C-1'-*phenyl*), 136.7 (C-4'-*phenyl*), 138.7 (C-10a), 163.2 (C-10b), 178.8 and 179.8 (C-5 and C-6). HRMS (ESI) calcd for $C_{20}H_{16}O_3$: 304.1099, Found: 304.1612

*2-(2,4-dimethylphenyl)-3,4-dihydro-2H-benzo[h] chromene-5,6-dione (**11c**)*



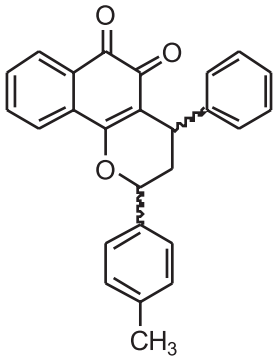
Orange solid, m.p.= 164-167 ^{0}C; IR (KBr, cm^{-1}): ν 1694, 1646, 1603, 1574, 1394, 1283, 1231, 1034, 998, 775; ^{1}H NMR ($CDCl_3$, 300 MHz): δ 1.99 (1H, dddd, *J* = 2.4, 3.0, 5.3 and 12.2 Hz, H-3a), 2.26 (1H, dddd, *J* = 2.4, 6.6, 7.8 and 12.2 Hz, H-3b), 2.36 (3H, s, $\underline{C}H_3$); 2.38 (3H, s, $\underline{C}H_3$), 2.59 (1H, ddd, *J* = 3.0, 6.6 and 8.7 Hz, H-4a), 2.85 (1H, ddd, *J* = 2.4, 5.3 and 8.7 Hz H-4b), 5.35 (1H, dd, *J* = 2.4 and 7.8 Hz, H-2), 7.10 (2H, d, *J* = 7.8 Hz, H-*orto and meta tolyl*), 7.33 (1H, d, *J* = 7.8 Hz, H-*meta tolyl*), 7.51 (1H, ddd, *J* = 1.2, 7.5 and 8.7 Hz,H-8), 7.61 (1H, ddd, *J* = 1.4, 7.5 and 9.0 Hz, H-9), 7.71 (1H, dd, *J* = 0.9 and 7.8 Hz, H-10), 8.06 (1H, dd, *J* = 1.4 and 7.5 Hz, H-7); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 19.2 ($\underline{C}H_3$), 19.2 (C-4), 21.2 ($\underline{C}H_3$), 27.5 (C-3), 77.9 (C-2), 114.2 (C-4a), 124.3 (C-5' *orto tolyl)*, 125.8 (C-6 and C-9), 127.3 (C-6'), 128.9 (C-3' *orto tolyl)*, 130.9 (C-9a), 131.8 (C-5a), 134.6 (C-1'),130.2 (C-6a), 132.4 (C-10a), 135.1 and 138.5 (C-2' and C-4'), 163.5 (C-10b), 178.7 and 179.8 (C-5 and C-10). HRMS (ESI) calcd for $C_{21}H_{18}O_3$: 318.1256, Found: 318.1892

*4-(4-nitrophenyl)-2-p-tolyl-3,4-dihydro-2H-benzo[h] chromene-5,6-dione (**11d**)*



Orange solid, m.p. = 232-235ºC; IR (KBr/cm^{-1}): 1696, 1645, 1600, 1570, 1513, 1344, 1287, 1233, 1168, 1091, 912, 736, 702. ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.19 (1H, dt, *J* = 2.4 and 14.4 Hz, H-3a *syn isomer*) and 2.27 (1H, dt, *J* = 11.2 and 14.4 Hz, H-3a *anti isomer*), 2.38 and 2.39 (3H, s, CH_3), 2.55 (1H, ddd, *J* = 5.9, 12.0 and 14.4 Hz, H-3b *syn isomer*) and 2.61 (1H, ddd, *J* = 2.2, 7.1 and 14.4 Hz, H-3b *anti isomer*), 4.31 (1H, dd, *J* = 7.1 and 11.0 Hz, H-4 *anti isomer*) and 4.48 (1H, dd, *J* = 2.4 and 5.9 Hz, H-4 *syn isomer*), 5.07 (1H, dd, *J* = 2.4 and 12.0 Hz, H-2 *syn isomer*) and 5.31 (1H, dd, *J* = 2.2 and 11.2 Hz, H-2 *anti isomer*), 7.25 (1H, d, *J* = 8.1 Hz, H-*meta p-tolyl*), 7.35 (1H, d, *J* = 8.1 Hz, H-*ortho p-tolyl*), 7.38 and 7.47 (1H, d, *J* = 8.8 Hz, H-*ortho 4-nitrophenyl*), 7.56-7.94 (1H, m, H-7), 7.56-7.94 (1H, m, H-8), 8.11 (1H, d, *J* = 8.8 Hz, H-*meta 4-nitrophenyl*), 8.09-8.23 (1H, m, H-9), 8.09-8.23 (1H, m, H-6). ^{13}C NMR (75 MHz, $CDCl_3$): δ 21.1 (CH_3), 34.9 and 38.4 (C-4), 36.7 and 39.8 (C-3), 80.0 (C-2), 115.9 (C-4a), 123.8 and 123.9 (C-3' *4-nitrophenyl*), 124.0 (C-2' *4-nitrophenyl*), 125.9 and 126.0 (C-3' *p-tolyl*), 127.7 (C-8), 128.6 (C-7), 128.8 and 129.0 (C-2' *p-tolyl*), 129.5 (C-10), 130.3 (C-6a), 130.4 (C-1' *p-tolyl*), 131.3 (C-9), 131.7 (C-4' *p-tolyl*), 135.0 (C-10a), 138.9 (C-4' *4-nitrophenyl*), 151.1 (C-1' *4-nitrophenyl*), 164.9 (C-10b), 177.6 (C-5), 178.7 (C-6). HRMS (ESI) calcd for $C_{26}H_{19}NO_5H^+$: 426.1336, Found: 426.4483.

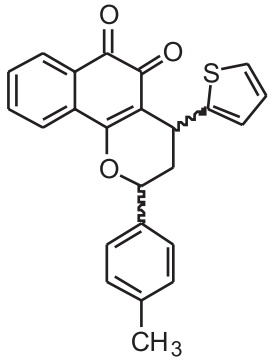
*4-Phenyl-2-p-tolyl-3,4-dihydro-2H-benzo[h]chromene-5,6-dione (**11e**)*



Orange solid, m.p. = 92-95 ºC; IR (KBr/cm^{-1}): 1696, 1653, 1600, 1568, 1382, 1284, 1231, 1164, 1086, 909, 767, 699. ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.13-2.37 (1H, m, H-3a, 2.38 and 2.39 (3H, s, CH_3), 2.59 (1H, ddd, *J* = 2.0, 7.3 and 14.4 Hz, H-3b), 4.20 (1H, dd, *J* = 7.1 and 11.2 Hz, H-4 *anti isomer*) and 4.42 (1H, dd, *J* = 1.7 and 5.4 Hz, H-4 *syn isomer*), 5.15 (1H, dd, *J* = 2.7 and 12.0 Hz, H-2 *syn isomer*) and 5.24 (1H, dd, *J* = 1.7 and 12.0 Hz, H-2 *anti* isomer), 7.13-7.38 (4H, m, *p-tolyl*), 7.13-7.38 (5H, m, Ph), 7.52-7.60 (1H, m, H-7), 7.64-7.70 (1H, m, H-8), 7.88-7.92 (1H, m, H-9), 8.07-8.10 (1H, m, H-6 *anti isomer*) and 8.12-8.15 (1H, m, H-6 *syn isomer*). ^{13}C NMR (75 MHz, $CDCl_3$): δ 21.1 (CH_3), 34.6 and 38.5 (C-4), 40.6 (C-3), 80.1 (C-2), 117.5 (C-4a), 124.5 (C-3' Ph), 126.0 and 126.1

(C-3' *p-tolyl*), 126.3 (C-2' Ph), 126.7 and 126.8 (C-4' Ph), 128.4 (C-8), 128.5 and 128.6 (C-7), 129.2 and 129.3 (C-2' *p-tolyl*), 130.2 (C-6a), 130.8 (C-10), 132.1 (C-1' *p-tolyl*), 134.8 (C-9), 135.6 (C-4' *p-tolyl*), 138.6 (C-10a), 143.3 (C-4' Ph), 164.1 (C-10b), 178.0 (C-5), 179.1 (C-6). HRMS (ESI) calcd for $C_{26}H_{20}O_3H^+$: 381.1485, Found: 381.4503.

*4-(thiophen-2-yl)-2-p-tolyl-3,4-dihydro-2H-benzo[h] chromene-5,6-dione (**11f**)*



Orange solid, m.p. = 83-87 ºC; IR (KBr/cm^{-1}): 1696, 1652, 1599, 1568, 1383, 1284, 1231, 1170, 1086, 907, 818, 722, 697. ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.28-2.43 (1H, m, H-3a), 2.40 (3H, s, CH_3), 2.68 (1H, ddd, 2.1, 7.1 and 14.4 Hz, H-3b), 4.57 (1H, dd, *J* = 7.1 and 11.0 Hz) and 4.65 (1H, dd, *J* = 1.0 and 3.2 Hz) H-4 conformers, 5.23 (1H, dd, *J* = 1.9 and 11.5 Hz) and 5.35 (1H, dd, *J* = 4.4 and 10.0 Hz) H-2 conformers, 6.89 and 6.90 (1H, dd, *J* = 1.0 and 3.4 Hz, H-3' *thiophen-2-yl* conformers), 6.86 and 6.95 (1H, dd, *J* = 3.7 and 5.1 Hz, H-4' *thiophen-2*-y conformers), 7.06 and 7.18 (1H, dd, *J* = 1.2 and 5.1 Hz, H-5' *thiophen-2-yl* conformers), 7.24 and 7.25 (1H, d, *J* = 8.0 Hz, H-*meta* conformers), 7.30 and 7.36 (1H, d, *J* = 8.0 Hz, H-*ortho* conformers), 7.54 and 7.57 (1H, td, *J* = 1.2 and 7.6 Hz, H-8 conformers), 7.65 and 7.67 (1H, dt, *J* = 1.2 and 7.6 Hz, H-9 conformers), 7.90 (1H, d, *J* = 7.6 Hz, H-10), 8.09 and 8.13 (1H, dd, *J* = 1.5 and 7.6 Hz, H-7 conformers). ^{13}C NMR (75 MHz, $CDCl_3$): δ 21.0 (CH_3), 30.1 and 33.4 (C-4), 37.1 and 40.9 (C-3), 76.6 and 80.0 (C-2), 115.2 and 117.2 (C-4a), 122.7 and 123.9 (C-5' *thiophen-2-yl*), 124.5 and 124.6 (C-3' *p-tolyl*), 125.0 (C-8), 126.0 and 126.1 (C-2' *p-tolyl*), 126.4 and 126.9 (C-10), 128.6 and 128.7 (C-7), 129.3 (C-4' *thiophen-2-yl*), 130.2 and 130.3 (C-6a), 130.9 and 131.0 (C-9), 131.7 and 131.9 (C-1' *p-tolyl*), 134.7 and 134.8 (C-3' *thiophen-2-yl*), 135.3 and 135.7 (C-4' *p-tolyl*), 138.5 and 138.6 (C-10a), 146.2 and 146.7 (C-2' *thiophen-2-yl*), 163.0 and 163.4 (C-10b), 177.7 and 178.0 (C-5), 179.0 (C-6). HRMS (ESI) calcd for $C_{24}H_{18}O_3SH^+$: 387.1049, Found: 387.4789.