Organic & Biomolecular Chemistry

Cite this: *Org. Biomol. Chem.*, 2011, **9**, 4782

www.rsc.org/obc

PAPER

Application of Nazarov type electrocyclization to access [6,5,6] and [6,5,5] core embedded new polycycles: an easy entry to tetrahydrofluorene scaffolds related to Taiwaniaquinoids and C-*nor*-D *homo*steroids†‡

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Received 18th October 2010, Accepted 12th January 2011
DOI: 10.1039/c0ob00892c

An easy, efficient and concise approach to tetrahydrofluorene [6,5,6]ABC tricyclic core embedded new polycycles has been achieved under relatively mild and catalytic Nazarov type electrocyclization conditions, using 2 mol% of $Sc(OTf)_3$ in anhydrous DCM (dichloromethane) at room temperature, with high yields. The generality of the reaction has been illustrated by synthesizing diverse polycycles embedded with rare heterotricyclic [6,5,5]ABC skeletons.

Introduction

Tetra-(and hexa-) hydrofluorene cores form an unusual [6,5,6]ABC tricyclic skeleton, found in Taiwaniaquinoids,[1] a class of natural products (Fig. 1) which are rather uncommon in nature. During the past decade, several of its members have received special attention among organic chemists owing to their bioactivities; for example Standishinal, obtained from the stem bark of Thuja standishii,[3] has demonstrated aromatase inhibitory activities whereas Taiwaniaquinones A,[1a] D[1b] and Taiwaniaquinols A,[1a] C[1d] are known to exhibit significant antitumor promoting activity against KB epidermoid carcinoma cancer cells. Besides, the [6,5,6] carbotricyclic core also features in steroidal alkaloids of C-*nor*-D-*homo* systems like jervine, veratramine and cyclopamines[2a] showing significant biological properties *viz.* severe teratogenic effects[2b] and inhibition of hedgehog signaling pathway activities.[2c]

In light of such promising bioactivities and the structural intrigue of tetra-(and hexa-) hydrofluorene skeleton, these classes of terpenoids and steroidal alkaloids have attracted diverse synthetic strategies towards total synthesis as well as construction of the unique tetra-(and hexa-) hydrofluorene carbotricyclic [6,5,6]ABC skeleton. In the literature several strategies are described to access 4a-substituted/unsubstituted hexahydrofluorene skeletons. These include the acid-catalyzed cyclization of substituted benzylcyclohexanols,[4] inter- and intramolecular [3 + 2] cycloadditions,[5] and the cyclization of an arylradical,[6] aryllithium,[7] or arylpalladium[8] tethered to a methylene cyclohexane. By contrast studies dealing with the synthesis of 4a-substituted/unsubstituted tetrahydrofluorenes are scarce[9] and, moreover, no reports could be found in the literature with a heteroatom impregnated in a carbotricyclic [6,5,6]ABC skeleton either with or without 4a-substitution in the aforementioned skeleton. Therefore, to us, it became highly desirable to design and synthesize the hetero [6,5,6] tricyclic system embedded new scaffolds resembling the structural framework of Taiwaniaquinoids and C-*nor*-D-*homo* steroids.

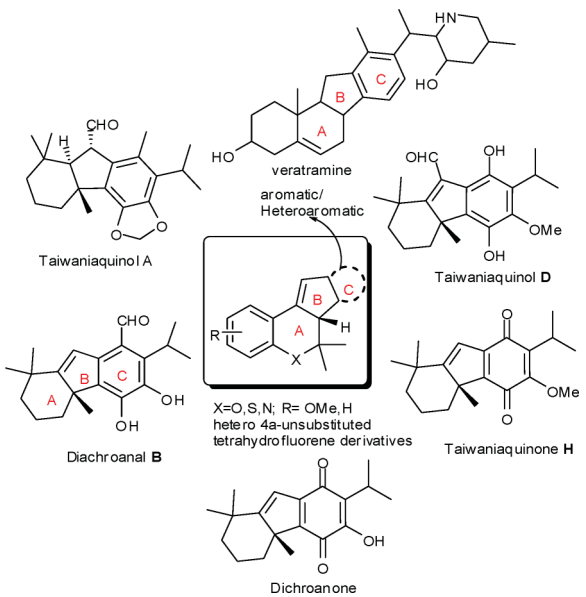

Fig. 1 Representative natural tetrahydrofluorene cores and our hetero 4a-unsubstituted tetrahydrofluorene skeletons.

Results and discussion

Towards our continued research interest in the application of Nazarov cyclization to access new classes of [6,5,6]ABC tricyclic core embedded heterocycles[10a] and the use of $Sc(OTf)_3$, an

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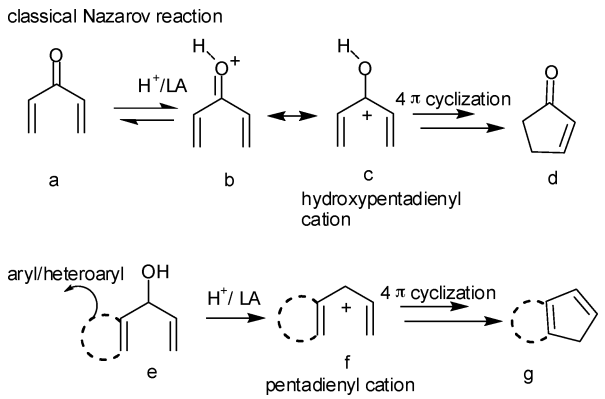
† Electronic supplementary information (ESI) available. See DOI: 10.1039/c0ob00892c

‡ CDRI communication number 8028

environmentally benign catalyst for C-C bond formation,[10b,10c] we embarked upon the idea to utilize pentadienyl cationic cyclization to access hetero 4a-unsubstituted tetrahydrofluorene skeleton embedded diverse heterocycles.

In the Nazarov reaction,[11] one of the key intermediates generated for cyclization is a hydroxy pentadienyl cation (**c**), which is generated upon activation from the action of Lewis or Brønsted acid to a divinyl ketone substrate. In an effort, to extend this type of electrocyclization, we sought to generate pentadienyl cation (**f**) from a different substrate, *i.e.* divinyl alcohol, to accomplish the desired goal (Scheme 1). A literature survey revealed only a few reports of such types of Nazarov cyclization using trifluoroacetic acid/$BF_3{\cdot}Et_2O$ as the catalyst.[12] However, a similar type of intramolecular Friedel–Crafts alkylation has been reported by Majetich *et al.*[13] and Alvarez-Manzaneda *et al.*[14] towards construction of a 4a-methyl tetrahydrofluorene skeleton using $SnCl_4$ and $BF_3{\cdot}Et_2O$ as catalyst.



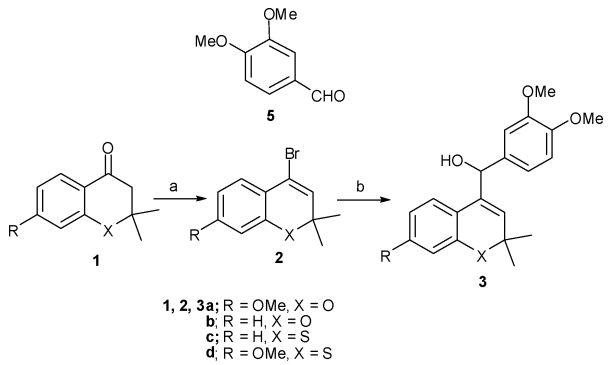
Scheme 1 Nazarov cyclization and proposed Nazarov type cyclization to accomplish desired scaffolds.

Herein, we report a concise and efficient synthetic route to construct heteroatom incorporated tricyclic [6,5,6]ABC skeleton embedded benzoannulated heterocycles under very mild reaction conditions using $Sc(OTf)_3$ as the cyclization promoter. This synthetic strategy has been further exploited to access diverse [6,5,5]ABC heterotricyclic core embedded new polycycles.

In analogy with the aryl vinyl ketone as a Nazarov substrate,[10a,15] we chose to use aryl vinyl alcohol **3** for the current studies; our work took impetus from the required divinyl alcohol substrate at hand which was synthesized from ketone **1** following the standard reaction conditions as depicted in Scheme 2.

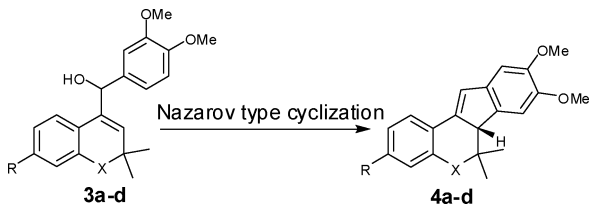
In the quest for hetero 4a-unsubstituted tetrahydrofluorene skeleton embedded polycycles, substrate **3a** and **3b** were subjected to reaction with various catalytic Lewis and protic acids, to search for the best catalyst required for such substrates (Table 1).

It was observed that the reaction proceeded with most of the catalysts screened during optimization, at room temperature using dichloromethane (DCM) as reaction solvent; however, noticeably better results were obtained in terms of yield when $Sc(OTf)_3$ was used as the reaction promoter. The mildness of the reaction can be judged by the fact that reaction occurred in only 30 min at room temperature using just 2 mol% of $Sc(OTf)_3$ as catalyst in anhydrous DCM to provide the coveted heterotricyclic [6,5,6]ABC skeleton embedded polycycles **4a** and **4b** with very high yields



Scheme 2 Synthesis of aryl vinyl alcohol **3**. [a] ***Reagents and Conditions***: (a) PBr_3, dry benzene, 60 °C, 24 h, 60–64%. (b) (i) *n*-BuLi, dry THF, –78 °C, N_2, 5–10 mins. ii) **5**, –78 °C to rt, 2 h, 55–60%.

Table 1 Catalyst optimization for Nazarov type cyclization



Entry	Substrate	Catalyst	Conditions	Time (min)	Yield[a]
1	**3a**	CF_3SO_3H	DCM, rt	5	60%
2	**3a**	H_2SO_4	DCM, rt	13	65%
3	**3b**	CF_3COOH	DCM, rt	15	68%
4	**3b**	*p*-TsOH	DCM, rt	12	65%
5	**3b**	$AlCl_3$	DCM, rt	10	62%
6	**3a**	$FeCl_3$	DCM, rt	16	75%
7	**3a**	$BF_3.Et_2O$	DCM, rt	14	77%
[b]**8**	**3b**	**$Sc(OTf)_3$**	**DCM, rt**	**30**	**89%**
9	**3b**	$AuCl_3$	DCM, rt	45	—
[c]10	**3c**	$Sc(OTf)_3$	benzene,rt	28	82%

[a] Isolated yield after column chromatography. [b] yield of **3a** (88%) [c] yield of **3d** (85%)

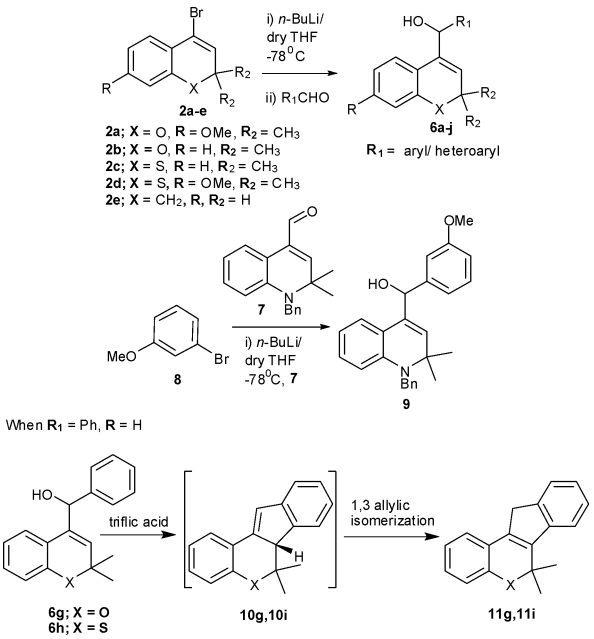
(88% and 89%). Stronger Lewis and Brønsted acids such as triflic acid (CF_3SO_3H), $AlCl_3$, H_2SO_4, $BF_3{\cdot}Et_2O$ required less reaction time for cyclization when used in stoichiometric amounts but with diminished yields. Treatment with $AuCl_3$ gave only decomposed product as observed on TLC.

Unfortunately, to our dismay substrate **3c** and **3d** failed to provide the cyclized product when DCM was used as reaction medium, although the starting material was consumed (as depicted by TLC); however, when cyclization was attempted using dry benzene as the solvent system, we were pleased to observe in each case a single spot on TLC, which proved to be the desired cyclized products **4c** and **4d** with yields of 82% and 85% respectively after NMR characterization. It was therefore concluded that for the sulfur embedded substrates, chlorinated solvents were not a suitable reaction medium in which to perform this cyclization.

It is worth mentioning that the other substrates (**3a**, **3b**) cyclized as efficiently in anhydrous benzene as in DCM without affecting the yield of the reaction. With the optimized reaction conditions at hand, we desired to check the generality of such type of cyclization on different set of heteroaryl or aryl vinyl alcohol substrates to

access heterotricyclic [6,5,6] or [6,5,5]ABC skeleton embedded heterocycles.

The substrates required for the purpose (**6a–j**, **9**) were synthesized, following similar reaction conditions as for Scheme 2 (Scheme 3).



Scheme 3 Synthesis of aryl/heteroaryl vinyl alcohols **6**, **9**.

In order to study the effect of substituents on cyclization to access heterotricyclic [6,5,6] skeletons, substrate **6g** and **6h** (entry 7, 9; Table 2) were subjected to the optimized reaction conditions, $Sc(OTf)_3$ in anhydrous DCM or benzene, but even after stirring for 24 h at room temperature no other spot apart from starting material could be detected on TLC. However, when we used triflic acid (1 eq.) in anhydrous benzene, surprisingly we obtained the isomerized cyclized product **11g** and **11i** rather than desired isomers **10g** and **10i**, in moderate yields of 67% and 65% respectively (Scheme 3).

Here we would like to mention that no unisomerized product (**10g**, **10i**) was observed in ^{1}H NMR analysis of crude reaction mixture. Further, nitrogen incorporated monosubstituted aryl substrate **9** (entry 8), cyclized smoothly using triflic acid (1 eq.) in anhydrous DCM to provide scaffold **10h** with good yield (79%); in fact it was also cyclized with $Sc(OTf)_3$ as catalyst in 24 h at room temperature. Subsequently, it was concluded that electron donating groups on aryl substrates activate the system towards efficient cyclization, while unsubstituted aryl substrates not only render the system to be sluggish in cyclization, but also lead to allylic isomerization, probably due to increase in acidity of the proton at the 4a position in heteroatom impregnated 4a*H*-tetrahydrofluorene derivatives (**10g**, **10i**) leading to thermodynamically more stable products (**11g**, **11i**). The dramatic shift of one of the gem dimethyl singlets and the presence of lone benzylic singlets in the ^{1}H NMR of the products **10** clearly distinguishes it from the isomerized products **11** and **6** (see supporting information†). Thereafter, an all carbocyclic system **6j** was checked for its propensity towards this type of cyclization and pleasingly furnished the product **10j** in 85% yield.[16]

We further attempted to extend the scope of this cyclization using heteroaryl substrates under the optimized reaction conditions; the results obtained, as summarized in (Table 2), present some interesting observations. The reactions proved to be mild enough as the heteroaryl substrates were consumed using just 2 mol% of $Sc(OTf)_3$ in anhydrous DCM or benzene at room temperature to provide the cyclized products. Amongst the indole based substrates, 2-substituted indole substrates (**6a**, **6b**, **6c**) cyclized promptly within a minute to furnish the desired heterotricyclic [6,5,5] skeleton embedded heterocycles (**10a**, **10b**, **10c**) in high yields (90–92%), whereas their 3-substituted counterpart (**6d**) took longer to cyclize (**10d**) with lesser yield (64%), which is probably due to the 3-position being the more reactive site in indoles as compared to the 2-position; however, the noticeable point was the drastic decrease in the yield. Disappointingly, 3-substituted benzothiophene (**6i**), 3-substituted thiophene (**6e**) and 2-substituted furan based substrate (**6f**) did not cyclize to give the desired product, although the starting material was consumed (as observed on TLC).

To the best of our knowledge this is the first report using heteroaromatic based substrates to optimize this type of Nazarov type cyclization, in the event leading to various heteroatom incorporated [6,5,5] tricyclic skeleton embedded hetero(poly)cycles.

Conclusion

In conclusion we have reported an easy, general and expedient route to access a variety of uncommon hetero [6,5,6]ABC tetrahydrofluorene cores resembling all carbotricyclic [6,5,6] tetrahydrofluorene cores present in Taiwaniaquinoids as well as in C-*nor*-D-*homo* steroids. Efforts have also been made to synthesize several hetero [6,5,5] tricyclic systems *via* Nazarov type cyclization. This is the first such heteroaromatic Nazarov system, showing excellent regioselectivity under very mild reaction conditions using just 2 mol% $Sc(OTf)_3$ and providing high yielding functionalized scaffolds that could serve as valuable building blocks towards Diversity Oriented Synthesis. Their bioevaluation and the asymmetric version of the Nazarov reaction in this system is currently underway in our lab and will be reported in due course.

Experimental section

All dry reactions were carried out under argon or nitrogen in oven-dried glassware using standard gas-tight syringes, cannulas and septa. All reagents and solvents were dried prior to use according to standard methods. Commercial reagents were used without further purification unless otherwise stated. Reactions were monitored on silica gel TLC plates (coated with TLC grade silica gel, obtained from Merck). The detecting agent used (for TLC) was iodine vapors. Column chromatography was performed over silica gel (100–200 mesh) procured from Qualigens (India) using freshly distilled solvents. Mass spectra were recorded using electron spray ionization (ESI-MS) or Fast atom bombardment spectra (FAB-MS) on a JEOL SX 102 spectrometer using argon/xenon as the FAB gas. IR spectra were recorded on a Perkin–Elmer FT-IR RXI spectrometer. ^{1}H NMR and ^{13}C NMR spectra were recorded on Bruker DPX-200 (operating at 200 MHz for ^{1}H and 50 MHz for ^{13}C) or DPX-300 (operating at 300 MHz for ^{1}H and 75 MHz for ^{13}C) spectrometer using $CDCl_3$ +CCl_4 and DMSO-d_6 as solvents.

Table 2 Nazarov type cyclization of aryl/heteroaryl substrates

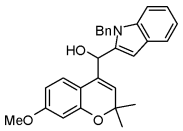
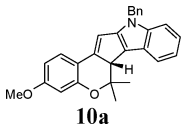
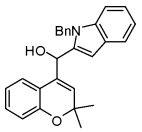
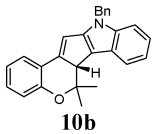
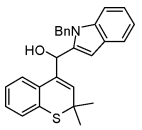
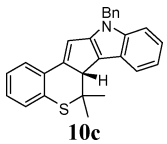
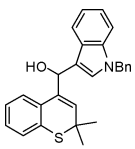
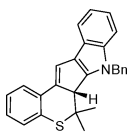
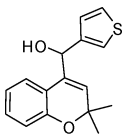
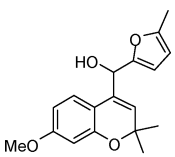
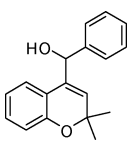
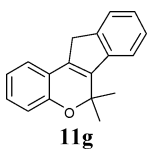
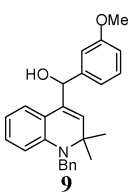
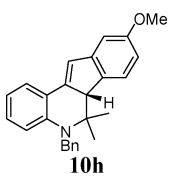
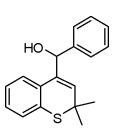
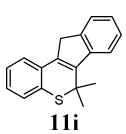
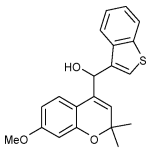
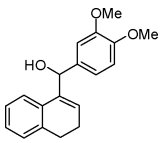
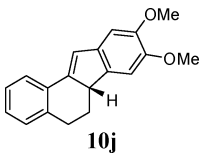
Entry	Substrate (**6**)	Product (**10**)	Time (min)	Yield (%)
[a]1	 **6a**	 **10a**	1	91%
[a]2	 **6b**	 **10b**	1	90%
[a]3	 **6c**	 **10c**	1	92%
[a]4	 **6d**	 **10d**	12	64%
[a]5	 **6e**	Decomposed	10	—
[a]6	 **6f**	Decomposed	16	—
[b]7	 **6g**	 **11g**	25	67%
[b]8	 **9**	 **10h**	20	79%
[b]9	 **6h**	 **11i**	30	65%

Table 2 *(Contd.)*

Entry	Substrate (**6**)	Product (**10**)	Time (min)	Yield (%)
[c]10	 **6i**	Uncharacterized product	—	—
[a]11	 **6j**	 **10j**	1	85%

[a] 2 mol% $Sc(OTf)_3$ in dry DCM/benzene at rt. [b] 1 equiv. Triflic acid in dry benzene at rt. [c] with all optimized reac[n] conditions in Table 1.

Tetramethylsilane (0.00 ppm) served as an internal standard in ^{1}H NMR and $CDCl_3$ (77.0 ppm), DMSO-d_6 (40.0) in ^{13}C NMR. All spectra were recorded at 25 °C. Coupling constants (J values) are given in hertz (Hz). Chemical shifts are expressed in parts per million (ppm).

Experimental procedures and characterization data

Typical procedure to prepare allyl alcohols

(3,4-Dimethoxyphenyl)(7-methoxy-2,2-dimethyl-2*H*-chromen-4-yl)methanol (3a). To a stirred solution of bromo substrate **2a** (500 mg, 1.40 mmol) in anhydrous THF (20 mL) at −78 °C and under N_2, *n*-BuLi (1.6 M in hexane, 1.2 mL, 1.40 mmol) was added. The resulting yellow solution was stirred at −78 °C for 5–10 min after which veratraldehyde **5** (192 mg, 1.16 mmol) in THF (2 mL) was added at the same temperature and stirred at room temperature for 1h. After quenching with water, THF was removed *in vacuo*. The mixture was extracted with ethyl acetate (3 × 20 mL), washed with brine and dried over Na_2SO_4. The concentrated extract was subjected to column chromatography on silica gel and elution with 20% ethyl acetate in hexane furnished alcohol **3a** (364 mg, 55%) as a viscous green oil, R_f = 0.61 (AcOEt/hexane, 20 : 80); IR (Neat): 3431, 2360, 1560, 1217,761, 670 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$ + CCl_4): δ 6.95–6.91 (m, 2H), 6.87 (d, 1H, J = 8.6 Hz), 6.80 (d, 1H, J = 7.9 Hz), 6.36 (d, 1H, J = 2.5 Hz), 6.26 (dd, 1H, J_1 = 2.6 Hz, J_2 = 8.6 Hz), 5.68 (s, 1H), 5.53 (s, 1H), 3.85 (s, 3H), 3.84 (s, 3H), 3.72 (s, 3H), 2.03 (s, br, 1H), 1.47 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$ + CCl_4): δ 160.4, 154.5, 149.2, 148.8, 134.4, 133.3, 124.8, 124.8, 119.5, 113.4, 111.2, 110.3, 106.5, 102.2, 76.0, 72.6, 55.8, 5.7, 55.0, 27.9; MS (ESI): m/z 339 [M–OH]$^+$; Anal. Calcd. for $C_{21}H_{24}O_5$: C, 70.77; H, 6.79. Found: C, 70.65; H, 6.85.

(3,4-Dimethoxyphenyl)(2,2-dimethyl-2*H*-chromen-4-yl)methanol (3b). As described for **3a**, **2b** (500 mg, 2.09 mmol) in THF (20 mL), *n*-BuLi (1.3 mL, 2.09 mmol) and veratraldehyde (312 mg, 1.88 mmol) in THF (2 mL) furnished **3b** (409 mg, 60%) as a viscous colourless oil, R_f = 0.59 (AcOEt/hexane, 20 : 80); IR (Neat): 3414, 3021, 2358, 1591, 1216,758, 668 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$ + CCl_4): δ 7.00–6.94 (m, 1H), 6.91–6.85 (m, 3H), 6.75–6.60 (m, 3H), 5.70 (s, 1H), 5.52 (s, 1H), 3.78 (s, 3H), 3.77 (s, 3H), 1.86 (s, br, 1H), 1.40 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$ + CCl_4): δ 153.1, 149.2, 148.9, 134.2, 133.4, 129.0, 127.5, 123.9, 120.5, 120.2, 119.5, 116.8, 111.1, 110.2, 75.7, 72.5, 55.8, 55.7, 27.9; MS (ESI): m/z 309 [M–OH]$^+$; Anal. Calcd. for $C_{20}H_{22}O_4$: C, 73.60; H, 6.79. Found: C, 73.71; H, 6.90.

(3,4-Dimethoxyphenyl)(2,2-dimethyl-2*H*-thiochromen-4-yl)-methanol (3c). As described for **3a**, **2c** (500 mg, 1.96 mmol) in THF (20 mL), *n*-BuLi (1.2 mL, 1.96 mmol) and veratraldehyde (293 mg, 1.76 mmol) in THF (2 mL) furnished **3c** (395 mg, 59%) as a viscous colourless oil, R_f = 0.48 (AcOEt/hexane, 20 : 80); IR (Neat): 3430, 3020, 2331, 1571, 1212, 760, 660 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$ + CCl_4): δ 7.30–7.27 (m, 1H), 7.19 (dd, 1H, J_1 = 1.0, J_2 = 7.8), 7.09–7.03 (m, 1H), 6.99–6.91 (m, 3H), 6.81–6.79 (m, 1H), 6.12 (s, 1H), 5.66 (s, 1H), 3.86 (s, 3H), 3.83 (s, 3H), 2.10 (s, br,1H), 1.49 (s, 3H), 1.47 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$ + CCl_4): δ 149.1, 148.6, 137.0, 134.8, 133.1, 132.8, 130.8, 127.9, 127.4, 127.3, 125.4, 119.4, 111.1, 110.2, 55.7, 55.6, 40.2, 28.9; MS (ESI): m/z 325 [M–OH]$^+$; Anal. Calcd. for $C_{20}H_{22}O_3S$: C, 70.15; H, 6.48. Found: C, 70.22; H, 6.57.

(3,4-Dimethoxyphenyl)(7-methoxy-2,2-dimethyl-2*H*-thiochromen-4-yl)methanol (3d). As described for **3a**, **2d** (500 mg, 1.75 mmol) in THF (20 mL), *n*-BuLi (1.1 mL, 1.75 mmol) and veratraldehyde (264 mg, 1.60 mmol) in THF (2 mL) furnished **3d** (378 mg, 58%) as a viscous colourless oil, R_f = 0.46 (AcOEt/hexane, 20 : 80); IR (Neat): 3429, 3021, 2329, 1569, 1213, 761, 669 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$ + CCl_4): δ 7.06 (d, 1H, J = 8.7 Hz), 6.85 (d, 2H, J = 7.9 Hz), 6.76–6.72 (m, 2H), 6.46 (dd, 1H, J_1 = 2.6 Hz, J_2 = 8.7 Hz), 5.92 (s, 1H), 5.53 (s, 1H), 3.82 (s, 3H), 3.79 (s, 3H), 3.72 (s, 3H), 2.28 (s, br,1H), 1.47 (s, 3H), 1.45 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$ + CCl_4): δ 158.4, 149.1, 148.6, 136.7, 135.0, 134.7, 130.3, 126.7, 123.9, 119.3, 112.6, 111.3, 111.1, 110.2, 74.2, 55.7, 55.5, 54.9, 40.6, 29.3, 29.1; MS (ESI): m/z 355 [M–OH]$^+$; Anal. Calcd. for $C_{21}H_{24}O_4S$: C, 67.72; H, 6.49. Found: C, 67.61; H, 6.57.

(1-Benzyl-1*H*-indol-2-yl)(7-methoxy-2, 2-dimethyl-2*H*-chromen-4-yl) methanol (6a). As described for **3a**, **2a** (500 mg, 1.96 mmol) in THF (20 mL), *n*-BuLi (1.2 mL, 1.96 mmol) and *N*-benzyl indole 2-carboxaldehyde (393 mg, 1.66 mmol) in THF (2 mL) furnished **6a** (418 mg, 54%) as a viscous colourless oil, R_f = 0.51 (AcOEt/hexane, 20 : 80); IR (Neat): 3417, 3010, 2330, 1211, 759, 670 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): δ 7.57 (d, 1H, J = 7.5 Hz), 7.33–7.02 (m, 8H), 6.47 (d, 2H, J = 7.7 Hz), 6.37 (d, 1H, J = 2.5 Hz), 6.14–6.10 (m, 1H), 5.71 (s, 1H), 5.67 (s, 1H), 5.54 (s, 2H), 3.71 (s, 3H), 2.00 (s, 1H), 1.46 (s, 3H), 1.43 (s, 3H); MS (FAB): m/z 410 $[M–OH]^+$; Anal. Calcd. for $C_{28}H_{27}NO_3$: C, 79.03; H, 6.40; N, 3.29. Found: C, 78.95; H, 6.34; N, 3.35.

(1-Benzyl-1H-indol-2-yl)(2, 2-dimethyl-2H-chromen-4-methanol (6b). As described for **3a**, **2b** (500 mg, 2.09 mmol) in THF (20 mL), *n*-BuLi (1.3 mL, 2.09 mmol) and *N*-benzyl indole 2-carboxaldehyde (594 mg, 1.88 mmol) in THF (2 mL) furnished **6b** (471 mg, 57%) as a viscous colourless oil, R_f = 0.54 (AcOEt/hexane, 20 : 80); IR (Neat): 3429, 3021, 2359, 1620, 1218, 765 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.59 (d, 2H, J = 7.7), 7.35–7.20 (m, 5H), 7.16–7.03 (m, 4H), 6.58 (d, 2H, J = 4.1), 6.49 (s, 1H), 5.89 (d, 1H, J = 1.1), 5.74 (s, 1H), 5.61 (d, 1H, J = 16.9), 5.53 (d, 1H, J = 16.8), 2.02 (s, br, 1H), 1.51 (s, 3H), 1.47 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 152.7, 139.5, 138.2, 137.8, 129.0, 128.8, 127.6, 127.5, 127.2, 126.2, 123.5, 122.4, 121.1, 120.4, 120.2, 119.8, 116.6, 109.6,102.6, 75.9, 65.3, 46.9, 27.7, 27.6; MS (ESI): m/z 396 $[M+1]^+$, 378 $[M–OH]^+$; Anal. Calcd. for $C_{27}H_{25}NO_2$: C, 82.00; H, 6.37; N, 3.54. Found: C, 81.92; H, 6.45; N, 3.61.

(1-Benzyl-1*H*-indol-2-yl)(2, 2-dimethyl-2*H*-thiochromen-4-yl) methanol (6c). As described for **3a**, **2c** (500 mg, 1.96 mmol) in THF (20 mL), *n*-BuLi (1.2 mL, 1.96 mmol) and *N*-benzyl indole 2-carboxaldehyde (418 mg, 1.78 mmol) in THF (2 mL) furnished **6c** (481 mg, 55%) as a viscous colourless oil, R_f = 0.56 (AcOEt/hexane, 20 : 80); IR (Neat): 3410, 3021, 2358, 1216, 762, 669 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.55 (d, 1H, J = 7.4 Hz), 7.32–7.16 (m, 6H), 7.12–6.95 (m, 4H), 6.78–6.69 (m, 2H), 6.37 (s, 1H), 6.15 (s, 1H), 5.73 (s, 1H), 5.59 (d, 1H, J = 16.8 Hz), 5.47 (d, 1H, J = 17.1 Hz), 2.03 (s, 1H), 1.49 (s, 3H), 1.42 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 149.7, 149.1, 140.8, 137.3, 133.5, 129.7, 128.8, 127.6, 127.4, 127.1, 126.6, 124.9, 124.8, 124.6, 120.4, 120.2, 119.2, 118.6, 115.0, 110.4, 55.1, 48.9, 48.3, 29.7, 22.7; MS (ESI): m/z 394 $[M–OH]^+$; Anal. Calcd. for $C_{27}H_{25}NOS$: C, 78.18; H, 6.12; N, 3.40. Found: C, 78.09; H, 6.23; N, 3.29.

(1-Benzyl-1*H*-indol-3-yl)(2,2-dimethyl-2H-thiochromen-4-yl)-methanol (6d). As described for **3a**, **2c** (500 mg, 1.96 mmol) in THF (20 mL), *n*-BuLi (1.2 mL, 1.96 mmol) and *N*-benzyl indole 3-carboxaldehyde (418 mg, 1.78 mmol) in THF (2 mL) furnished **6d** (462 mg, 53%) as a viscous colourless oil, R_f = 0.58 (AcOEt/hexane, 20 : 80); IR (Neat): 3430, 3021, 1569, 1216, 759, 670 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.73–7.67 (m, 2H), 7.35 (d, 1H, J = 1.5 Hz), 7.29–7.17 (m, 5H), 7.16–7.09 (m, 4H), 7.07–6.95 (m, 4H), 5.53 (s, 2H), 3.93 (d, 1H, J = 1.4 Hz), 1.60 (s, 3H), 1.06 (s, 3H); MS (ESI): m/z 394$[M–OH]^+$; Anal. Calcd for $C_{27}H_{25}NOS$: C, 78.80; H, 6.12; N, 3.40. Found: C, 78.91; H, 6.01; N, 3.54.

(2,2-Dimethyl-2*H*-chromen-4-yl)(thiophen-3-yl)methanol (6e). As described for **3a**, **2b** (500 mg, 2.09 mmol) in THF (20 mL), *n*-BuLi (1.3 mL, 2.09 mmol) and thiophene 3-carboxaldehyde (210 mg, 1.88 mmol) in THF (2 mL) furnished **6e** (313 mg, 55%) as a viscous colourless oil, R_f = 0.53 (AcOEt/hexane, 20 : 80); IR (Neat): 3404, 3021, 2359, 1216, 760 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.30–7.26 (m, 2H), 7.14–7.06 (m, 3H), 6.85–6.73 (m, 2H), 5.81 (s, 1H), 5.72 (s, 1H), 2.38 (s, br, 1H), 1.47 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 153.0, 143.2, 133.4, 129.0, 127.4, 126.5, 126.1, 123.7, 122.6, 120.4, 120.1, 116.7, 75.7, 68.9, 27.7, 27.6; MS (ESI): m/z 255 $[M–OH]^+$; Anal. Calcd. for $C_{16}H_{16}O_2S$: C, 70.56; H, 5.92. Found: C, 70.67; H, 6.05.

(2, 2-Dimethyl-2*H*-chromen-4-yl)(Phenyl) methanol (6g). As described for **3a**, **2b** (500 mg, 1.85 mmol) in THF (20 mL), *n*-BuLi (1.2 mL, 1.85 mmol) and benzaldehyde (176 mg, 1.66 mmol) in THF (2 mL) furnished **6g** (322 mg, 58%) as a viscous colourless oil, R_f = 0.56 (AcOEt/hexane, 20 : 80); IR (Neat): 3430, 3019, 2360, 1210, 759, 669 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.48 (d, 1H, J = 1.6), 7.45 (d, 1H, J = 1.0), 7.41–7.29 (m, 3H), 7.12–7.03 (m, 2H), 6.83 (dd, 1H, J_1 = 1.0, J_2 = 8.0), 6.75 (m, 1H), 5.84 (d, 1H, J = 1.2), 5.69 (d, 1H, J = 2.5), 2.17 (d, 1H, J = 3.8), 1.50 (s, 3H), 1.50 (s, 3H); MS (ESI): m/z 249 $[M–OH]^+$; Anal. Calcd. for $C_{18}H_{18}O_2$: C, 81.17; H, 6.81; Found: C, 81.19; H, 6.91.

(2, 2-Dimethyl-2*H*-thiochromen-4-yl)(Phenyl) methanol (6h). As described for **3a**, **2c** (500 mg, 1.96 mmol) in THF (20 mL), *n*-BuLi (1.2 mL, 1.96 mmol) and benzaldehyde (188 mg, 1.78 mmol) in THF (2 mL) furnished **6h** (317 mg, 51%) as a viscous colourless oil, R_f = 0.54 (AcOEt/hexane, 20 : 80); IR (Neat): 3429, 3016, 2361, 1213, 764, 671 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.45–7.42 (m, 2H), 7.38–7.36 (m, 1H), 7.33–7.24 (m, 4H), 7.11–7.06 (m, 1H), 7.01–6.96 (m, 1H), 6.12 (s, 1H), 5.77 (s, 1H), 2.11 (s, br, 1H), 1.50 (s, 3H), 1.48 (s, 3H); MS (ESI): m/z 265 $[M–OH]^+$; Anal. Calcd for $C_{18}H_{18}OS$: C, 76.56; H, 6.42; Found: C, 76.69; H, 6.38.

(7-Methoxy-2, 2-dimethyl-2*H*-chromen-4-yl)(5-methylfuran-2-yl) methanol (6f). As described for **3a**, **2a** (500 mg, 1.85 mmol) in THF (20 mL), *n*-BuLi (1.2 mL, 1.85 mmol) and 5-methyl furfural (183 mg, 1.66 mmol) in THF (2 mL) furnished **6f** (312 mg, 56%) as a viscous colourless oil, R_f = 0.52(AcOEt/hexane, 20 : 80); IR (Neat): 3432, 3023, 2360, 1213, 760 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 6.98 (d, 1H, J = 8.4), 6.43 (d, 1H, J = 2.5), 6.36 (dd, 1H, J_1 = 2.5, J_2 = 8.5), 6.07 (d, 1H, J = 2.8), 5.89 (d, 1H, J = 2.1), 5.77 (d, 1H, J = 0.8), 5.65 (s, 1H), 3.77 (s, 3H), 2.31 (s, 3H), 2.17 (s, br, 1H), 1.47 (s, 6H); MS (ESI): m/z 283 $[M–OH]^+$; Anal. Calcd. for $C_{18}H_{20}O_4$: C, 71.98; H, 6.71; Found: C, 72.90; H, 6.59.

(1-Benzyl-2,2-dimethyl-1,2-dihydroquinolin-4-yl)(3-methoxyphenyl)methanol (9). As described for **3a**, **8** (500 mg, 2.70 mmol) in THF (20 mL), *n*-BuLi (1.7 mL, 2.70 mmol) and **7** (678 mg, 2.45 mmol) in THF (2 mL) furnished **9** (566 mg, 54%) as a viscous colourless oil, R_f = 0.51(AcOEt/hexane, 20 : 80); IR (Neat): 3438, 3022, 2356, 1213, 769 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.34–7.25 (m, 5H), 7.21 (d, 1H, J = 6.4 Hz), 7.10–7.07 (m, 2H), 6.937 (d, 1H, J = 7.6 Hz), 6.87–6.82 (m, 2H), 6.44 (t, 1H, J = 7.5 Hz), 6.28 (d, 1H, J = 8.3 Hz), 5.73 (s, 1H), 5.69 (s, 1H), 4.52 (s, 2H), 3.80 (s, 3H), 2.04 (s, br, 1H), 1.44 (s, 3H), 1.43 (s, 3H); MS (ESI): m/z 368 $[M–OH]^+$; Anal. Calcd. for $C_{26}H_{27}NO_2$: C, 81.01; H, 7.06; N, 3.63. Found: C, 81.13; H, 6.96; N, 3.75.

Benzo[b]thiophen-3-yl (7-methoxy-2, 2-dimethyl-2H-chromen-4-yl) methanol (6i). As described for **3a**, **2a** (500 mg, 1.85 mmol) in THF (20 mL), *n*-BuLi (1.2 mL, 1.85 mmol) and thianaphthene

3-carbaldehyde (269 mg, 1.66 mmol) in THF (2 mL) furnished **6i** (412 mg, 63%) as a viscous colourless oil, $R_f = 0.51$(AcOEt/hexane, 20 : 80); IR (Neat): 3438, 3022, 2356, 1213, 769 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.98–7.93 (m, 1H), 7.90–7.85 (m, 1H), 7.45–7.37 (m, 3H), 6.98 (d, 1H, J = 8.5 Hz), 6.45 (d, 1H, J = 2.6 Hz), 6.33 (dd, 1H, J_1 = 2.6, J_2 = 8.6 Hz), 6.03 (s, 1H), 5.70 (d, 1H, J = 1.0 Hz), 3.76 (s, 3H), 2.22 (s, br, 1H), 1.48 (s, 3H), 1.47 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 160.6, 154.5, 140.9, 137.6, 136.6, 132.4, 125.5, 125.0, 124.6, 124.5, 124.2, 122.9, 122.3, 113.5, 106.7, 102.4, 76.3, 67.5, 55.2, 27.8, 27.7; MS (ESI): m/z 335 $[M–OH]^+$; Anal. Calcd. for $C_{21}H_{20}O_3S$: C, 71.56; H, 5.72; Found: C, 71.43; H, 6.90.

(3,4-Dihydronaphthalen-1-yl)(3,4-dimethoxyphenyl)methanol (6j). As described for **3a**, **2e** (200 mg, 0.95 mmol) in THF (15 mL), *n*-BuLi (0.60 mL, 0.95 mmol) and veratraldehyde (164 mg, 0.86 mmol) in THF (2 mL) furnished **6j** (74 mg, 52%) as viscous colourless oil, R_f = 0.32(AcOEt/hexane, 20 : 80); IR (Neat): 3433, 3018, 2354, 1214, cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.14–7.11 (m, 1H), 7.07–6.99 (m, 3H), 6.92–6.86 (m, 2H), 6.73 (d, 1H, J = 8.3 Hz), 6.11–6.09 (m, 1H), 5.63 (s, br, 1H), 3.77 (s, 3H), 3.76 (s, 3H), 2.69 (t, 2H, J = 7.8 Hz), 2.30–2.24 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 148.9, 148.5, 138.3, 136.7, 135.0, 133.0, 127.6, 126.9, 126.8, 126.2, 123.5, 119.3, 111.0, 110.3, 73.7, 55.8, 55.8, 28.2, 22.9; MS (ESI): m/z 289 $[M–OH]^+$; Anal. Calcd. for $C_{19}H_{20}O_3$: C, 77.00; H, 6.80; Found: C, 77.13; H, 6.94.

Typical procedure for Nazarov type cyclization

(±)-3,8,9-Trimethoxy-6,6-dimethyl-6,6a-dihydroindeno[1,2-c]-chromene (4a). To a stirred solution of substrate **3a** (100 mg, 0.28 mmol) in anhydrous DCM or benzene (10 mL) at room temperature, was added $Sc(OTf)_3$ (2 mol%) at the same temperature and the reaction was stirred vigorously until completion (as observed on TLC). It was then neutralized by saturated Na_2CO_3 solution at 0 °C, extracted with DCM or ethyl acetate (3 × 10 mL) and dried over anhydrous Na_2SO_4. After evaporation of the solvent, the residue was subjected to column chromatography on silica gel and elution with 10% ethyl acetate in hexane furnished the cyclized product **4a** (83 mg, 88%) as a colourless semi solid, R_f = 0.66 (AcOEt/hexane, 10: 90); IR (KBr): 1451, 1216,1039, 760 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6): δ 7.52 (d, 1H, J = 8.3 Hz), 7.06 (s, 1H), 6.99 (s, 1H), 6.90 (d, 1H, J = 1.6 Hz), 6.52 (dd, 1H, J_1 = 2.6 Hz, J_2 = 8.6 Hz), 6.40 (dd, 1H, J_1 = 2.4 Hz, J_2 = 7.9 Hz), 3.78 (s, 1H), 3.77 (s, 3H), 3.76 (s, 3H), 3.72 (s, 3H), 1.80 (s, 3H), 0.68 (s, 3H); MS (ESI): m/z 339 $[M+1]^+$; Anal. Calcd. for $C_{21}H_{22}O_4$: C, 74.54; H, 6.55. Found: C, 74.45; H, 6.44.

(±)-8,9-Dimethoxy-6,6-dimethyl-6,6a-dihydroindeno[1,2-c]chromene (4b). As described for **4a**, **3b** (100 mg, 0.31 mmol) in anhydrous DCM (10 mL), and $Sc(OTf)_3$ (2 mol%), furnished **4b** (84 mg, 89%) as a colourless semi solid, R_f = 0.68 (AcOEt/hexane, 10 : 90); IR (KBr): 1449, 1217, 1029, 759 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6): δ 7.64–7.61 (m, 1H), 7.17–7.05 (m, 4H), 6.93 (d, 1H, J = 7.5 Hz), 6.84 (d, 1H, J = 8.1 Hz), 3.79 (s, 3H), 3.78 (s, 3H), 3.65 (s, 1H), 1.83 (s, 3H), 0.68 (s, 3H); ^{13}C NMR (75 MHz, DMSO-d_6): δ 152.9, 149.3, 147.4, 140.5, 138.9, 134.6, 129.5, 124.8, 123.7, 121.1, 120.3,117.5, 109.4, 105.7, 81.9, 56.5, 56.1, 55.4, 28.1, 19.3; MS (ESI): m/z 309 $[M+1]^+$; Anal. Calcd. for $C_{20}H_{20}O_3$: C, 77.90; H, 6.54. Found: C, 78.03; H, 6.65.

(±)-8, 9-Dimethoxy-6, 6-dimethyl-6, 6a-dihydroindeno [1, 2-c] thiochromene (4c). As described for **4a**, **3c** (100 mg, 0.30 mmol) in anhydrous benzene (10 mL), and $Sc(OTf)_3$ (2 mol%), furnished **4c** (77 mg, 82%) as a colourless semi solid, R_f = 0.69 (AcOEt/hexane, 10 : 90); IR (KBr): 1438, 1216, 1028, 763 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6): δ 7.79–7.75 (m, 1H), 7.27 (d, 1H, J = 1.37 Hz), 7.16 (s, 1H), 7.14–7.06 (m, 3H), 7.04 (s, 1H), 3.88 (s, 3H), 3.81 (s, 3H), 3.80 (s, 1H), 1.80 (s, 3H), 0.82 (s, 3H); MS (ESI): m/z 325 $[M+1]^+$; Anal. Calcd. for $C_{20}H_{20}O_2S$: C, 74.04; H, 6.21. Found: C, 74.14; H, 6.17.

(±)-3,8,9-Trimethoxy-6,6-dimethyl-6,6a-dihydroindeno[1,2-c]-thiochromene (4d). As described for **4a**, **3d** (100 mg, 0.27 mmol) in anhydrous benzene (10 mL), and $Sc(OTf)_3$ (2 mol%), furnished **4d** (80 mg, 85%) as a colourless semi solid, R_f = 0.75 (AcOEt/hexane, 10 : 90); IR (KBr): 1460, 1217, 1044, 764 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6): δ 7.73 (d, 1H, J = 9.3 Hz), 7.16 (s, 2H), 7.01 (s, 1H), 6.74 (d, 1H, J = 2.6 Hz), 6.72 (s, 1H), 3.83 (s, 1H), 3.79 (s, 3H), 3.78 (s, 3H), 3.75 (s, 3H), 1.80 (s, 3H), 0.82 (s, 3H); ^{13}C NMR (75 MHz, DMSO-d_6): δ 159.5, 149.7, 147.3, 143.8, 138.7, 135.0, 134.8, 127.6, 125.1, 122.9, 113.1, 110.8, 105.7, 58.4, 56.9, 56.5, 56.1, 49.0, 28.9, 23.7; MS (ESI): m/z 355 $[M+1]^+$;Anal. Calcd. for $C_{21}H_{22}O_3S$: C, 71.16; H, 6.26. Found: C, 71.24; H, 6.17.

(±)-11-Benzyl-3-methoxy-6,6-dimethyl-6a,11-dihydro-6*H*-5-oxa-11-aza- benzo[5,6]pentaleno[2,1-b]naphthalene (10a). As described for **4a**, **6a** (100 mg, 0.23 mmol) in anhydrous DCM (10 mL), and $Sc(OTf)_3$ (2 mol%), furnished **10a** (87 mg, 91%) as a greenish semi solid, R_f = 0.74 (AcOEt/hexane, 10 : 90); IR (KBr): 1602, 1450, 1217, 1041, 762 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6): δ 7.52 (d, 1H, J = 8.6 Hz), 7.51–7.44 (m, 2H), 7.33–7.18 (m, 5H), 7.15 (d, 1H, J = 1.5 Hz), 7.07–6.97 (m, 2H), 6.55 (dd, 1H, J_1 = 2.5, J_2 = 8.6 Hz), 6.47 (d, 1H, J = 2.5 Hz), 5.5 (s, 2H), 3.74 (s, 4H), 1.92 (s, 3H), 0.76 (s, 3H); ^{13}C NMR (75 MHz, DMSO-d_6): δ 160.7, 154.3, 151.4, 145.8, 140.5, 138.5, 129.1, 127.8, 127.4, 125.6, 124.4, 120.4, 120.0, 118.1, 115.7, 113.9, 111.9, 111.4, 108.5, 102.3, 82.7, 55.7, 51.6, 47.9, 29.7, 19.4; MS (ESI): m/z 408 $[M+1]^+$; Anal. Calcd. for $C_{28}H_{25}NO_2$: C, 82.53; H, 6.18; N, 3.44. Found: C, 82.42; H, 6.08; N, 3.52.

(±) 11-Benzyl-6, 6-dimethyl-6a, 11-dihydro-6*H*-5-oxa-11-aza-benzo [5, 6] pentaleno [2, 1-b] naphthalene (10b). As described for **4a**, **6b** (100 mg, 0.25 mmol) in anhydrous DCM (10 mL), and $Sc(OTf)_3$ (2 mol%), furnished **10b** (86 mg, 90%) as a greenish semi solid, R_f = 0.78 (AcOEt/hexane, 10 : 90); IR (KBr): 1605, 1451, 1216,1039, 760 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6): δ 7.61 (d, 1H, J = 7.8 Hz), 7.50 (s, 2H), 7.31–7.14 (m, 7H), 7.10–7.03 (m, 2H), 6.96–6.85 (m, 2H), 5.54 (s, 2H), 3.81 (s, 1H), 1.93 (s, 3H), 0.75 (s, 3H); ^{13}C NMR (75 MHz, DMSO-d_6): δ 152.9, 150.9, 145.5, 140.7, 138.3, 129.3, 128.9, 127.7, 127.2, 124.4, 124.3, 121.1, 120.8, 118.2, 117.5, 116.9, 114.1, 111.4, 82.4, 51.6, 47.9, 29.7, 19.2; MS (ESI): m/z 378 $[M+1]^+$; Anal. Calcd. for $C_{27}H_{23}NO$: C, 85.91; H, 6.14; N, 3.71. Found: C, 85.84; 6.06; N, 3.63.

(±)-11-Benzyl-6,6-dimethyl-6a,11-dihydro-6*H*-5-thia-11-aza-benzo[5,6]pentaleno[2,1-b]naphthalene (10c). As described for **4a**, **6c** (100 mg, 0.24 mmol) in anhydrous benzene (10 mL), and $Sc(OTf)_3$ (2 mol%), furnished **10c** (88 mg, 92%) as a greenish viscous oil, R_f = 0.79 (AcOEt/hexane, 10 : 90); IR (KBr): 1451, 1216,1039, 760 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6): δ 7.84–7.81 (m, 1H), 7.61 (d, 1H, J = 1.2 Hz), 7.57–7.54 (m, 1H),

7.50–7.47 (m, 1H), 7.33–7.28 (m, 2H), 7.26–7.10 (m, 6H), 7.08–7.02 (m, 2H), 5.56 (s, 2H), 4.02 (s, 1H), 1.89 (s, 3H), 0.85 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 150.1, 148.4, 140.8, 138.5, 132.9, 129.9, 129.1, 127.9, 127.8, 127.4, 127.2, 125.8, 125.3, 124.7, 120.6, 120.5, 119.3, 118.0, 117.1, 111.555.0, 48.8, 47.9, 29.7, 22.9; MS (ESI): *m/z* 394 $[M+1]^+$; Anal. Calcd. for $C_{27}H_{23}$ NS: C, 82.40; H, 5.89; N, 3.56. Found: C, 82.51; H, 5.78; N, 3.44.

(±) 7-Benzyl-6,6-dimethyl-6a,7-dihydro-6*H*-5-thia-7-aza-benzo[4,5]pentaleno[2,1-a]naphthalene (10d). As described for **4a**, **6d** (100 mg, 0.24 mmol) in anhydrous benzene (10 mL), and $Sc(OTf)_3$ (2 mol%), furnished **10c** (61 mg, 64%) as a colourless semi solid, R_f = 0.79 (AcOEt/hexane, 10 : 90); IR (KBr): 1427, 1216, 1104, 761 cm^{-1}. ^{1}H NMR (300 MHz, DMSO-d_6): δ 7.83–7.80 (m, 1H), 7.60 (d, 1H, *J* = 1.5 Hz), 7.56–7.54 (m, 1H), 7.49–7.46 (m, 1H), 7.32–7.27 (m, 2H), 7.24–7.16 (m, 4H), 7.15–7.10 (m, 2H), 7.08–7.01 (m, 2H), 5.54 (s, 2H), 4.01 (d, 1H, *J* = 1. Hz), 1.88 (s, 3H), 0.85 (s, 3H); MS (ESI): *m/z* 394 $[M+1]^+$; Anal. Calcd. for $C_{27}H_{23}$ NS: C, 82.40; H, 5.89; N, 3.56. Found: C, 82.28; H, 6.01; N, 3.44.

(±)-5-Benzyl-9-methoxy-6,6-dimethyl-6,6a-dihydro-5*H*-indeno-[1,2-c]quinoline (10h). As described for **4a**, **9** (100 mg, 0.26 mmol) in anhydrous DCM (10 mL), and triflic acid (0.0225 mL, 0.26 mmol), furnished **10h** (75 mg, 79%) as a a colourless semi solid, R_f = 0.67 (AcOEt/hexane, 10 : 90); IR(KBr) : 3022, 2361, 1218, 763 cm^{-1}; ^{1}H NMR (300 MHz, DMSO-d_6): δ 7.55 (dd, 1H, J_1 = 1.6, J_2 = 7.9 Hz), 7.48–7.34 (m, 5H), 7.27–7.22 (m, 1H), 7.02–6.95 (m, 2H), 6.70–6.62 (m, 2H), 6.34 (d, 1H, *J* = 8.4 Hz), 4.87 (d, 1H, *J* = 18.7 Hz), 4.19 (d, 1H, *J* = 17.3 Hz), 3.78 (s, 3H), 3.71 (s, 1H), 1.74 (s, 3H), 0.62 (s, 3H); MS (ESI): *m/z* 368 $[M+1]^+$; Anal. Calcd. for $C_{26}H_{25}$ NO: C, 84.98; H, 6.86; N, 3.81. Found: C, 85.08; H, 6.72; N, 3.93.

6, 6-Dimethyl-6, 11-dihydroindeno [1, 2-c] chromene (11g). As described for **4a**, **6g** (100 mg, 0.37 mmol) in anhydrous benzene (10 mL), and triflic acid (0.0321 mL, 0.37 mmol), furnished **11g** (62 mg, 67%) as a colourless semi solid, R_f = 0.84 (AcOEt/hexane, 10 : 90); IR (KBr): 2364, 1667, 1595, 670 cm^{-1}; ^{1}H NMR (300 MHz, DMSO-d_6): δ 7.49 (d, 2H, *J* = 6.9 Hz), 7.31–7.08 (m, 5H), 6.92–6.78 (m, 2H), 3.70 (s, 2H), 1.68 (s, 6H) ^{13}C NMR (75 MHz, DMSO-d_6): δ 152.6, 144.4, 142.3, 134.7, 129.9, 127.5, 125.7, 125.1, 124.2, 121.7, 121.3, 120.9, 116.5, 79.3, 35.9, 28.2; MS (ESI): *m/z* 249 $[M+1]^+$; Anal. Calcd. for $C_{18}H_{16}$ O: C, 87.06; H, 6.49; Found: C, 87.16; H, 6.38.

6, 6-Dimethyl-6, 11-dihydroindeno [1, 2-c] thiochromene (11i). As described for **4a**, **6h** (100 mg, 0.35 mmol) in anhydrous benzene (10 mL), and triflic acid (0.032 mL, 0.35 mmol), furnished **11i** (60 mg, 65%) as a colourless semi solid, R_f = 0.82 (AcOEt/hexane, 10 : 90); IR (KBr): 2361, 1684, 669 cm^{-1}; ^{1}H NMR (300 MHz, DMSO-d_6): δ 7.70 (d, 1H, *J* = 7.3 Hz), 7.52–7.49 (m, 2H), 7.27–7.20 (m, 5H), 3.80 (s, 2H), 1.73 (s, 6H); MS (ESI): *m/z* 265 $[M+1]^+$; Anal. Calcd. for $C_{18}H_{16}$ S : C, 81.77; H, 6.10;. Found: C, 81.87; H, 5.98.

(±)-8, 9-Dimethoxy-6,6a-dihydro-5*H*-benzo[a]fluorene (10j). As described for **4a**, **6j** (70 mg, 0.24 mmol) in anhydrous DCM (5 mL), and $Sc(OTf)_3$ (2 mol%), furnished **10j** (54 mg, 85%) as a colourless semi solid, R_f = 0.67 (AcOEt/hexane, 10 : 90); IR (KBr): 1453, 1213, 1037 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.68 (d, 1H, *J* = 7.7 Hz), 7.21–7.17 (m, 3H), 7.08 (s, 1H), 6.99 (s, 1H), 6.92 (s, 1H), 3.93 (s, 3H), 3.92 (s, 3H), 3.47 (dd, 1H, J_1 = 3.5, J_2 = 13.2), 3.13–3.08 (m, 2H), 2.63–2.59 (m, 1H), 1.49–1.43 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 148.7, 147.7, 147.1, 139.6, 137.9, 136.4, 132.5, 129.0, 127.1, 126.3, 124.2, 122.0 107.2, 104.7, 56.3, 56.1, 49.1, 30.6, 28.7; MS (ESI): *m/z* 279 $[M+1]^+$; Anal. Calcd. for $C_{19}H_{18}O_2$: C, 81.99; H, 6.52; Found: C, 82.11; H, 6.65.

Acknowledgements

The authors thank the Department of Science and Technology (DST) (SR/S1/OC-74/2009), New Delhi, India for financial support and SAIF, CDRI for providing analytical data. Ritesh thanks CSIR for the fellowship.

Notes and References

1 (*a*) W. Lin, J. Fang and Y. Cheng, *Phytochemistry*, 1995, **40**, 871; (*b*) W. Lin, J. Fang and Y. Cheng, *Phytochemistry*, 1996, **42**, 1657; (*c*) K. Kawazoe, M. Yamamoto, Y. Takaishi, G. Honda, T. Fujita, E. Sezik and E. Yesilada, *Phytochemistry*, 1999, **50**, 493; (*d*) C. Chang, S. Chien, S. Lee and Y. Kuo, *Chem. Pharm. Bull.*, 2003, **51**, 1420; (*e*) C. Chang, J. Chang, C. Kuo, W. Pan and Y. Kuo, *Planta Med.*, 2005, **71**, 72; (*f*) M. Iwamoto, H. Ohtsu, H. Tokuda, H. Nishino, S. Matsunaga and R. Tanaka, *Bioorg. Med. Chem.*, 2001, **9**, 1911; (*g*) T. Minami, M. Iwamoto, H. Ohtsu, H. Ohishi, R. Tanaka and A. Yoshitake, *Planta Med.*, 2002, **68**, 742; (*h*) J. R. Hanson, *Nat. Prod. Rep.*, 2004, **21**, 312.

2 (*a*) H.-J. Li, Y. Jiang and P. Li, *Nat. Prod. Rep.*, 2006, **23**, 735; (*b*) W. Gaffield, in *Studies in Natural Products Chemistry*, ed. Atta-ur-Rahman, Elsevier Science B.V., Amsterdam, 2000, **23**, 563; (*c*) P. Heretsch, L. Tzagkaroulaki and A. Giannis, *Angew. Chem., Int. Ed.*, 2010, **49**, 3418 and citations therein.

3 H. Ohtsu, M. Iwamoto, H. Ohishi, S. Matsunaga and R. Tanaka, *Tetrahedron Lett.*, 1999, **40**, 6419.

4 (*a*) U. R. Ghatak and J. Chakravarty, *Tetrahedron Lett.*, 1966, **7**, 2449; (*b*) U. R. Ghatak, J. Chakravarty and A. K. Banerjee, *Tetrahedron*, 1968, **24**, 1577; (*c*) U. R. Ghatak, J. Chakravarty, R. Dasgupta and P. J. Chakraborti, *J. Chem. Soc., Perkin Trans. 1*, 1975, 2438; (*d*) J. Chakravarty, R. Dasgupta, J. K. Ray and U. R. Ghatak, *Proc. Indian Acad. Sci.*, 1977, **86A**, 317; (*e*) P. J. Chakraborti, S. Ghosh, P. B. Kanjilal, G. O. S. V. Satyanarayana and U. R. Ghatak, *Indian J. Chem.*, 1979, **18B**, 183.

5 S. R. Angle and D. O. Arnaiz, *J. Org. Chem.*, 1992, **57**, 5937.

6 (*a*) H. Ishibashi, T. Kobayashi, S. Nakashima and O. Tamura, *J. Org. Chem.*, 2000, **65**, 9022; (*b*) H. Ishibashi, T. Kobayashi and D. Takamatsu, *Synlett*, 1999, 1286.

7 W. F. Bailey, T. Daskapan and S. Rampalli, *J. Org. Chem.*, 2003, **68**, 1334.

8 J. K. Mukhopadhyaya, S. Pal and U. R. Ghatak, *Synth. Commun.*, 1995, **25**, 1641.

9 (*a*) T. Lomberget, E. Bentz, D. Bouyssi and G. Balme, *Org. Lett.*, 2003, **5**, 2055; (*b*) C. Roussel, L. Shaima and A. Chemlal, *Bull. Soc. Chim. Fr.*, 1988, 688.

10 (*a*) R. Singh, M. K. Parai and G. Panda, *Org. Biomol. Chem.*, 2009, **7**, 1858; (*b*) R. Singh and G. Panda, *Org. Biomol. Chem.*, 2010, **8**, 1097; (*c*) S. K. Das, R. Singh and G. Panda, *Eur. J. Org. Chem.*, 2009, 4757.

11 For recent work and reviews on Nazarov chemistry, see: (*a*) M. Harmata, *Chemtracts*, 2004, **17**, 416; (*b*) M. A. Tius, *Eur. J. Org. Chem.*, 2005, **11**, 2193; (*c*) A. J. Frontier and C. Collison, *Tetrahedron*, 2005, **61**, 7577; (*d*) H. Pellissier, *Tetrahedron*, 2005, **61**, 6479; (*e*) L. Bartali, P. Larini, A. Guarna and E. G. Occhiato, *Synthesis*, 2007, 1733.

12 (*a*) K. C. Rupert, C. C. Liu, T. T. Nguyen, M. A. Whitener and J. R. Sowa, *Organometallics*, 2002, **21**, 144; (*b*) C. D. Smith, G. Rosocha, L. Mui and R. A. Batey, *J. Org. Chem.*, 2010, **75**, 4716; (*c*) G. A. Olah, G. Asensio and H. Mayr, *J. Org. Chem.*, 1978, **43**, 1518; (*d*) G.-Y. Lin, C.-Y. Yang and R.-S. Liu, *J. Org. Chem.*, 2007, **72**, 6753; (*e*) J. A. Malona, K. Cariou and A. J. Frontier, *J. Am. Chem. Soc.*, 2009, **131**, 7560; (*f*) P. Cordier, C. Aubert, M. Malacria, E. Lacote and V. Gandon, *Angew. Chem.*, 2009, **121**, 8913.

13 J. M. Shimkus, G. Majetich, 58th Southeastern Regional Meeting of the American Chemical Society, Augusta, GA, November 1-4, 2006. Abstract # SRM06-633.
14 E. Alvarez-Manzaneda, R. Chahboun, E. Cabrera, E. Alvarez, A. Haidour, R. Alvarez-Manzaneda, R. Meneses, H. Es-Samti and A. Ferna'ndez, *J. Org. Chem.*, 2009, **74**, 3384.
15 (*a*) K. F. Cheng, K. P. Chan and T. F. Lai, *J. Chem. Soc., Perkin Trans. 1*, 1991, 2461; (*b*) C. Song, D. Knight and M. Whatton, *Org. Lett.*, 2006, **8**, 163; (*c*) J. A. Malona, J. M. Colbourne and A. J. Frontier, *Org. Lett.*, 2006, **8**, 5661.
16 Bromo compound **2e** was synthesized from commercially available α-tetralone, following similar reaction conditions as in Scheme 2, and was used immediately due to its unstable nature.

