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PAPER

Synthesis of oxabicyclo[3.3.1]nonenes and substituted tetrahydropyrans *via* (3,5)-oxonium-ene reaction†

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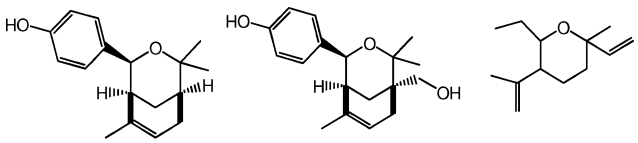
An efficient methodology for the synthesis of oxabicyclo[3.3.1]nonenes and substituted tetrahydropyrans has been developed in moderate yields from the reaction of geraniol with aldehydes and epoxides promoted by boron trifluoride etherate.

Introduction

Oxabicyclo[3.3.1]nonenes and selected derivatives (Fig. 1, **A-B**) are known to behave as estrogen receptor ligands.[1] Oxabicyclo[3.3.1]nonenes are prepared by the reaction of aromatic aldehydes with olefin-containing compounds in acidic media.[1,2] The low yield and multistep reactions are the major drawback of these methods.[1,2] On the other hand, tetrahydropyrans are found in many biologically active natural products and pharmaceuticals.[3] Alkyl substituted tetrahydropyrans (Fig. 1, **C**) are used as aroma and flavouring substances for pharmaceuticals, cosmetics and food stuff.[4] They are generally prepared by hetero-Diels–Alder methods,[5] manipulation of carbohydrates,[6] Prins cyclization,[7] and intramolecular Michael reactions.[8] Of these, the Prins cyclization is generally used for tetrahydropyran synthesis. Oxonium-ene reactions are important in carbon-carbon and carbon-heteroatom bond-forming reactions in organic synthesis[9] and have been exploited in synthetic and medicinal chemistry.[10] The (3,5)-oxonium-ene reaction has been used for the synthesis of cyclic ethers.[11] Recently we have developed a methodology for the synthesis of oxabicyclo[3.3.1]nonanone *via* (3,5)-oxonium-ene reaction.[11a] Although this reaction provides oxabicyclo[3.3.1]nonanone, it fails to give oxabicyclo[3.3.1]nonene, which has significant biological properties.[1] We now wish to disclose a methodology for the synthesis of oxabicyclo[3.3.1]nonene and substituted tetrahydropyrans from the reaction of aldehydes with geraniol *via* (3,5)-oxonium-ene reaction mediated by boron trifluoride etherate.

Results and discussion

In continuation of our interest in oxygen heterocyclic compounds,[12] we were in search of an efficient methodology for the synthesis of oxabicyclo[3.3.1]nonene. Taking clues from our previous work[11a] and the literature,[2] and the fact that geraniol gives α-terpineol under acidic conditions; we envisioned that treatment of geraniol **1** with boron trifluoride etherate would provide carbocation **6**, which after cyclization and subsequent nucleophilic attack by aldehyde would give oxocarbenium ion **8**. The oxocarbenium ion **8** after (3,5)-oxonium-ene cyclization would give the oxabicyclic compound **3**. Accordingly, geraniol was reacted with benzaldehyde in dry dichloromethane using boron trifluoride etherate as the Lewis acid and 2,2,6-trimethyl-4-phenyl-3-oxabicyclo[3.3.1]non-6-ene **3** was obtained in 52% yield along with an inseparable mixture of two substituted tetrahydropyrans **4** and **5** with 25% overall yield. The reaction is generalized as shown in Table 1.



A **B** **C**

Fig. 1 Biologically active cyclic ethers

To prove its general applicability different types of aromatic and aliphatic aldehydes were subjected to react with geraniol and it was observed that aromatic aldehydes and cyclohexanecarboxaldehyde give oxabicyclo[3.3.1]nonene as the major product (Table 1), whereas simple aliphatic aldehydes give tetrahydropyrans as major product (Scheme 2). This might be due to the better nucleophilicity and smaller size of the aliphatic aldehydes compared to the aromatic aldehydes, which makes it an easy approach to the carbocation **6** rather than allowing it to transform into **7** (Scheme 1). Among the aromatic aldehydes, simple benzaldehyde and 4-nitro benzaldehyde gave a small amount of tetrahydropyrans. The formation of some tetrahydropyrans in the case of benzaldehyde and p-nitrobenzaldehyde might be due to the electron-withdrawing effect of phenyl and p-nitrophenyl ring, which destabilizes the oxocarbenium ion. On the other hand, the electron-donating groups on aromatic ring (entry c-d, k-l) stabilize the oxo-carbenium ion.[12b] However, the formation of only one tetrahydropyran in case of 4-nitrobenzaldehyde is

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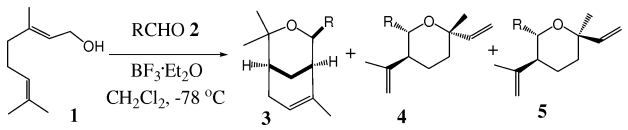
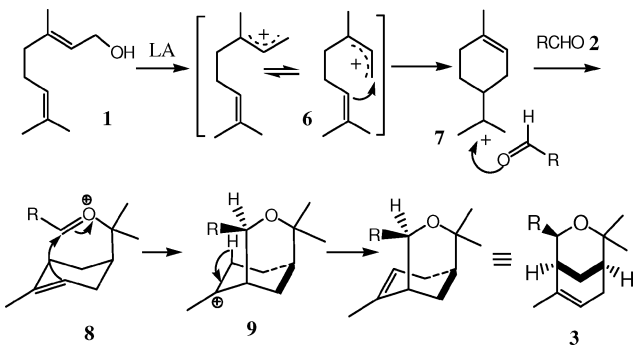
† Electronic supplementary information (ESI) available: General experimental methods, ^{1}H and ^{13}C NMR spectra of all compounds. See DOI: 10.1039/c1ob05172e

Table 1 Reaction of geraniol with aldehydes



Sl. No.	Aldehyde R =	Time/h	Product ratio 3 : 4 : 5[a]	Product **3** Yield (%)[b]	Product **4**+**5** Yield (%)[c]
a	$C_6H_5^-$	2.5	4 : 2 : 1	52	25
b	*p*-Cl-$C_6H_4^-$	2.5	1 : 0 : 0	70	0
c	*p*-Br-$C_6H_4^-$	2.5	1 : 0 : 0	70	0
d	*p*-F-$C_6H_4^-$	2.5	1 : 0 : 0	68	0
e	*p*-NO_2-$C_6H_4^-$	3	2 : 1 : 0	50	15
f	*o*-NO_2-$C_6H_4^-$	3	1 : 0 : 0	54	0
g	$C_{10}H_7$ (2-Naphthyl)	2.5	1 : 0 : 0	55	0
h	C_6H_4-CH=CH^-	2	1 : 0 : 0	62	0
i	*p*-NO_2-C_6H_4-CH=CH^-	2	1 : 0 : 0	55	0
j	*p*-MeO_2C-$C_6H_5^-$	3	1 : 0 : 0	57	0
k	*p*-HO-$C_6H_4^-$	3	1 : 0 : 0	60	0
l	*p*-CH_3-$C_6H_4^-$	2.5	1 : 0 : 0	68	0
m	Cyclo-C_6H_{11}	2	1 : 0 : 0	62	0
n	$C_2H_5^-$	2	1 : 3 : 1	8	65
o	$C_3H_7^-$	2	1 : 3 : 1	8	65
p	$(CH_3)_2CHCH_2^-$	2	1 : 3 : 1	10	67
q	$CH_3(CH_2)_5^-$	2	1 : 3 : 1	15	60
r	$CH_3(CH_2)_{14}^-$	2	1 : 3 : 1	10	62

[a] Ratios are determined by ^1H NMR of crude product. [b] Yields refer to isolated yield. The compounds are characterized by IR, ^1H, ^{13}C and mass spectroscopy. [c] Total isolated yield of **4** and **5**.



Scheme 1 Proposal for the formation of oxabicyclic compounds.

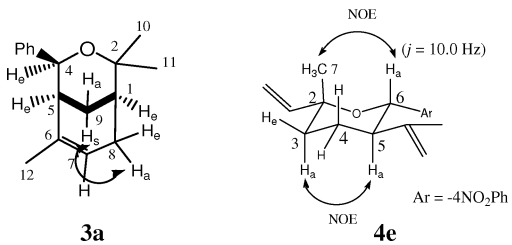


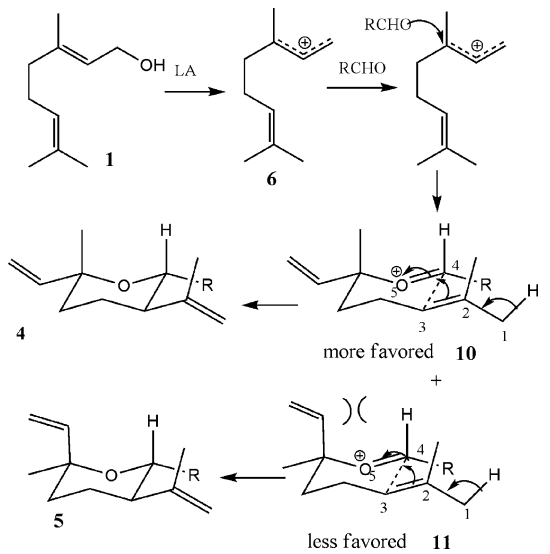
Fig. 2 NOE of **3a** and **4e**.

quite uncommon. The structure and stereochemistry of bicyclic compounds and substituted tetrahydropyrans were determined by ^1H NMR and NOE experiments (Fig. 2). The coupling constant of H_{4e} (4.88 ppm) proton of **3a** is 2.0 Hz, which is typical for vicinal diequatorial coupling and therefore, H_{4e} and H_{5e} (2.19–2.21 ppm) are in equatorial position. This is in accordance with the Dreiding model where H_{5e} proton cannot be axial. Again the coupling constant between H_{1e} (1.56 ppm) and H_{8a} (2.32–2.43 ppm) is 3.2 Hz which indicates that one proton is in an axial position and the other in an equatorial position. The presence of a strong NOE between H_{8a} and H_{9syn} (1.73 ppm) confirms that they are in a 1,3-diaxial position. Therefore, H_{1e} is in an equatorial position. This is also in accordance with the Dreiding model. Thus H_{5e} and H_{1e} are in equatorial positions and hence the fusion between two rings is *cis* fusion (**3a**, Fig. 2). Similarly, the stereochemistry of substituted tetrahydropyran **4e** was determined as follows. The coupling constant of H_{6a} (4.56 ppm) is 10.0 Hz and it indicates that H_{5a} (2.11–2.19 ppm) and H_{6a} are in axial positions. The presence of NOE between H_{6a} and C-7 methyl protons (1.31 ppm) and between H_{5a} and H_{3a} (1.80–1.92) further confirms that the protons H_{5a} and H_{6a} are in axial position and are *trans* to each other, whereas H_{6a} and C-7 methyl protons are *cis* (**4e**, Fig. 2).

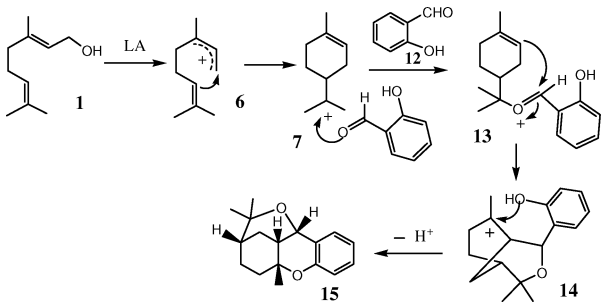
The mechanism of the formation of tetrahydropyrans can be represented as shown in Scheme 2. Here the smaller aliphatic aldehydes attack the carbocation **6** to form more favored transition state **10**, which after cyclization gives the more stable isomer **4** as a major product and a minor product **5** from the less favored transition state **11** (Scheme 2).[11b]

In the case of salicyldehyde **12** a tetracyclic compound **15** was obtained in 40% yield. The formation of **15** can be explained as shown in Scheme 3. Here carbocation **14** is attacked by phenolic group to give tetracyclic compound **15**. The structure and stereochemistry of the compound was determined from ^1H NMR, COSY and NOE experiments.

The reaction of geraniol with epoxides was also performed and the results are summarized in Table 2. It was observed that monosubstituted terminal epoxides are non-reactive, whereas the 2,2-disubstituted and styrene oxides are active and give



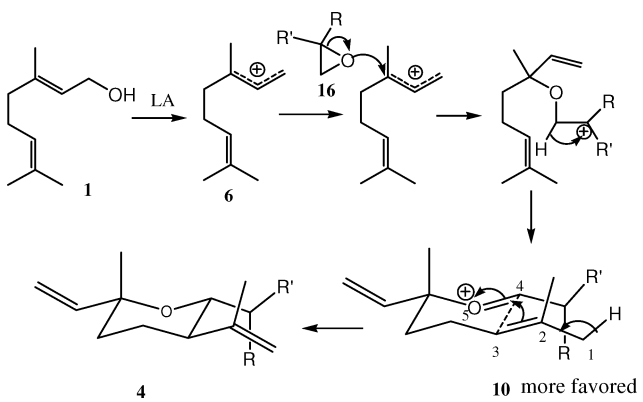
Scheme 2 Mechanism for the formation of tetrahydropyrans.



Scheme 3 Reaction with salicyldehyde.

good to moderate yields.[11a] Interestingly monosubstituted benzylic terminal epoxide (entry 5) was also found to give corresponding tetrahydropyrans. The formation of substituted tetrahydropyrans **18c–18g** and **19c–19g** from epoxides **16c–16g** are in accordance with the facts already discussed; but the formation of bicyclic compound **17b** in case of 2,2-dimethyl oxirane **16b** is not clear (Table 2).

The mechanism of the formation of tetrahydropyrans can be explained as follows. The carbocation **6** is attacked by epoxide to give oxocarbenium intermediate **10**, which after oxonium-ene cyclization gives tetrahydropyran **4** (Scheme 4). In the case of 2,2-dimethyl oxirane the carbocation **6** rearranges to **7** and is then attacked by epoxide to give the oxabicyclic compound **17b**.



Scheme 4 Mechanism of the reaction with epoxide.

Conclusions

In summary, an efficient methodology for the synthesis of oxabicyclo[3.3.1]nonenes and substituted tetrahydropyrans has been developed from readily available starting material in moderate to good yields.

Experimental section

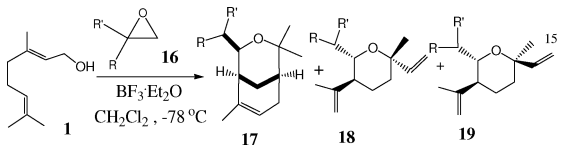
General procedure for the synthesis of oxabicyclo and substituted tetrahydropyran from aldehyde

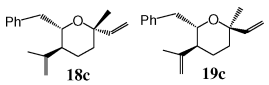
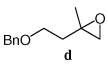
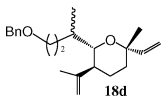
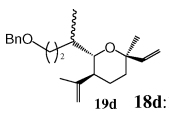
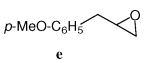
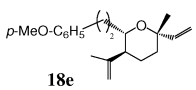
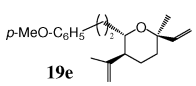
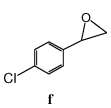
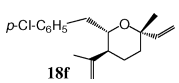
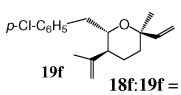
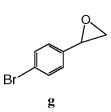
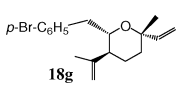
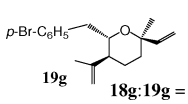
To a solution of geraniol (1 mmol, 1 equiv.) in dry CH_2Cl_2 (2 mL) at −78 °C was added boron trifluoride etherate (1.2 mmol, 1.2 equiv.). To this solution aldehyde (1 mmol, 1 equiv) in dry CH_2Cl_2 (2 mL) was added drop by drop over 5 min. The reaction mixture was stirred at that temperature for a specified time. The progress of the reaction was monitored by TLC with hexane as eluent. After completion of the reaction, the solvent was removed by rotary evaporator. The resultant residue was quenched with saturated solution of $NaHCO_3$. The product was extracted with ethyl acetate and then washed with brine and water. The organic layer was dried (Na_2SO_4) and evaporated to leave the crude product, which was purified by short column chromatography over silica gel to give the title compounds. All compounds were obtained as colourless oil or semisolid and therefore boiling points were not determined.

Synthesis of 2,2,6-trimethyl-4-phenyl-3-oxabicyclo[3.3.1]non-6-ene (3a)

To a solution of geraniol (154 mg, 1 mmol) in dry CH_2Cl_2 (2 mL) at −78 °C, was added boron trifluoride etherate (170 mg, 1.2 mmol). To this solution benzaldehyde (106 mg, 1.0 mmol) in dry CH_2Cl_2 (2 mL) was added drop by drop over 5 min. The reaction mixture was stirred at that temperature for 2.5 h. The progress of the reaction was monitored by TLC with hexane as eluent. After completion of the reaction, the solvent was removed by rotary evaporator. The resultant residue was quenced with saturated $NaHCO_3$ solution. The product was extracted with ethyl acetate and then washed with brine and water. The organic layer was dried (Na_2SO_4) and evaporated to leave the crude product, which was purified by short column chromatography over silica gel to give **3a** as a colourless oil (126 mg, 52%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.86 (m, 3 H), 1.34 (s, 3 H), 1.40 (s, 3 H), 1.56 (ddd, J = 6.4, 3.2 and 3.2 Hz, 1 H), 1.73 (ddd, J = 12.4, 3.2 and 3.2 Hz, 1 H), 2.08 (dddq, J = 18.8, 6.3, 3.2 and 2.4 Hz, 1 H), 2.19–2.21 (m, 1 H), 2.32–2.43 (m, 2 H), 4.88 (d, J = 2.0 Hz, 1 H), 5.40–5.44 (m, 1 H), 7.17–7.20 (m, 1 H), 7.25–7.28 (m, 2 H), 7.30–7.33 (m, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 24.2, 24.3, 27.9, 28.5, 28.9, 34.2, 41.8, 74.4, 75.5, 123.5, 125.8, 126.7, 128.0, 133.4, 143.1; IR (KBr, Neat): 2935, 1450, 1379, 1207, 1084, 1057, 755, 700 cm^{-1}. HRMS (APCI) cald. for $C_{17}H_{22}O$ (M^+) requires 242.1671; found 242.1663.

Table 2 Reaction of geraniol with epoxides



Sl. No.	Epoxide	Time/h	Products	%Yield[a]
1	 a	12	No reaction	0
2	 b	3	 17b	45
3	 c	3	 18c 19c 18c:19c = 3:2[b]	52
4	 d	3	 18d  19d 18d:19d = 2:1[b]	48
5	 e	3	 18e  19e 18e:19e = 2:1[b]	45
6	 f	3	 18f  19f 18f:19f = 3:2[b]	48
7	 g	3	 18g  19g 18g:19g = 3:2[b]	48

[a] Yields refer to isolated yield. The compounds are characterized by IR, ^{1}H, ^{13}C NMR and mass spectroscopy. [b] Ratios are determined by ^{1}H NMR of crude products.

General procedure for the synthesis of oxabicyclo and substituted tetrahydropyran from epoxide

To a solution of geraniol (1 mmol, 1 equiv.) in dry CH_2Cl_2 (2 mL) at −78 °C, was added boron trifluoride etherate (1.2 mmol, 1.2 equiv.). To this solution epoxide (2 mmol, 2 equiv) in dry CH_2Cl_2 (2 mL) was added drop by drop over 5 min. Then the temperature of the reaction was brought to room temperature. The reaction mixture was stirred at that temperature for a specified time. The progress of the reaction was monitored by TLC with

hexane as eluent. After completion of the reaction, the solvent was removed by rotary evaporator. The resultant residue was quenched with saturated solution of $NaHCO_3$. The product was extracted with ethyl acetate and then washed with brine and water. The organic layer was dried (Na_2SO_4) and evaporated to leave the crude product, which was purified by short column chromatography over silica gel to give the title compounds. All compounds were obtained as colourless oil or semisolid and therefore boiling points were not determined.

4-Isopropyl-2,2,6-trimethyl-3-oxabicyclo[3.3.1]non-6-ene (17b)

To a solution of geraniol (154 mg, 1 mmol) in dry CH_2Cl_2 (2 mL) at –78 °C, was added boron trifluoride etherate (170 mg, 1.2 mmol). To this solution 1,2-epoxy-2-methylpropane (144 mg, 2.0 mmol) in dry CH_2Cl_2 (2 mL) was added drop by drop over 5 min. The temperature was slowly brought to room temperature. The reaction mixture was stirred at that temperature for 3 h. The progress of the reaction was monitored by TLC with hexane as eluent. After completion of the reaction, the solvent was removed by rotary evaporator. The resultant residue was quenched with saturated $NaHCO_3$ solution. The product was extracted with ethyl acetate and then washed with brine and water. The organic layer was dried (Na_2SO_4) and evaporated to leave the crude product, which was purified by short column chromatography over silica gel to give **17b** as a colourless oil (94 mg, 45%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.92 (d, J = 6.4 Hz, 3 H), 0.94 (d, J = 6.4 Hz, 3 H), 1.21 (s, 3 H), 1.26 (s, 3 H), 1.46 (ddd, J = 6.4, 3.2 and 3.2 Hz,1 H), 1.49–1.60 (m, 1 H), 1.65 (ddd, J = 12.4, 3.2 and 3.2 Hz, 1 H), 1.75 (s, 3 H), 2.00–2.12 (m, 2H), 2.14–2.20 (m, 1H), 2.28–2.38(m, 1H), 3.14 (d, J = 10.0 Hz, 1 H), 5.52 (brs, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 19.5, 20.7, 24.2, 25.4, 28.2, 28.7, 29.1, 30.8, 34.3, 35.6, 75.1, 80.2, 124.4, 133.7; IR (KBr, Neat) 2956, 2931, 1642, 1458, 1377, 1226, 1067, 1050, 886, 801 cm^{-1}. HRMS (APCI) cald. for $C_{14}H_{24}O$ (M^+) requires 208.1827; found 208.1832.

4-(4-Chlorophenyl)-2,2,6-trimethyl-3-oxabicyclo[3.3.1]-non-6-ene, 3b

Colourless oil (194 mg, 70%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.88 (m, 3 H), 1.32 (s, 3 H), 1.38 (s, 3 H), 1.56 (ddd, J = 6.0, 3.2 and 3.2 Hz, 1 H), 1.73 (ddd, J = 12.4, 3.2 and 3.2 Hz, 1 H), 2.08 (dddq, J = 19.2, 6.4, 3.2 and 2.4 Hz, 1 H), 2.15–2.18 (m, 1 H), 2.30–2.42 (m, 2 H), 4.84 (d, J = 2.0 Hz, 1 H), 5.44 (brs, 1 H), 7.22–727 (m, 4 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 24.2, 24.4, 27.9, 28.4, 28.8, 34.1, 41.6, 73.9, 75.7, 123.9, 127.4, 128.2, 132.4, 132.9, 141.7; IR (KBr, Neat): 2933, 1635, 1464, 1380, 1226, 1075, 1053, 801, 677 cm^{-1}. HRMS (APCI) cald. for $C_{17}H_{21}ClO$ (M^+) requires 276.1281; found 276.1269.

4-(4-Bromophenyl)-2,2,6-trimethyl-3-oxabicyclo[3.3.1]non-6-ene, 3c. Colourless oil (225 mg, 70%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.88 (m, 3 H), 1.32 (s, 3 H), 1.37 (s, 3 H), 1.56 (ddd, J = 6.0, 3.2 and 2.8 Hz, 1 H), 1.73 (ddd, J = 12.4, 3.2 and 2.8 Hz, 1 H), 2.08 (dddq, J = 18.8, 6.0, 3.2 and 2.8 Hz, 1 H), 2.15–2.17 (m, 1 H), 2.30–2.42 (m, 2 H), 4.81 (d, J = 2.0 Hz, 1 H), 5.40–5.45 (m, 1 H), 7.19 (d, J = 8.8 Hz, 2 H), 7.39 (d, J = 8.8 Hz, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 24.1, 24.5, 27.8, 28.4, 28.8, 34.0, 41.6, 73.9, 75.7, 120.5, 123.9, 127.7, 131.1, 132.9, 142.2; IR (KBr, Neat): 2932, 1461, 1369, 1204, 1072, 1056, 806, 801 cm^{-1}. HRMS (APCI) cald. for $C_{17}H_{21}BrO$ (M^+) requires 320.0776; found 320.0789.

4-(4-Fluorophenyl)-2,2,6-trimethyl-3-oxabicyclo[3.3.1]non-6-ene, 3d. Colourless oil (177 mg, 68%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.87 (s, 3 H), 1.33 (s, 3 H), 1.39 (s, 3 H), 1.54–1.62 (m, 1 H), 1.72 (ddd, J = 12.4, 3.2 and 3.2 Hz, 1 H), 2.05–2.16 (m, 2 H), 2.31–2.42 (m, 2 H), 4.85 (s, 1H), 5.40–5.45 (m, 1 H), 6.96 (t, J = 8.4 Hz, 2H), 7.28 (t, J = 7.6 Hz, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 24.2, 24.3, 27.9, 28.4, 28.9, 34.1, 41.7, 73.9, 75.7, 114.8 (d, J = 21.3 Hz), 123.8, 127.4 (d, J = 7.7 Hz), 133.0, 138.9, 162.0 (d, J = 242.5 Hz); ^{19}F NMR (376 MHz, $CDCl_3/C_6F_6$): δ –220.69–(–220.77) (m, 1 F); IR (KBr, Neat): 2932, 1626, 1509, 1377, 1227, 1074, 1056, 824, 798 cm^{-1}. HRMS (APCI) cald. for $C_{17}H_{21}FO$ (M^+) requires 260.1576; found 260.1565.

4-(4-Nitrophenyl)-2,2,6-trimethyl-3-oxabicyclo[3.3.1]non-6-ene, 3e. Colourless oil (144 mg, 50%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.82 (m, 3 H), 1.35 (s, 3 H), 1.40 (s, 3 H), 1.59 (ddd, J = 6.0, 3.2 and 2.8 Hz, 1 H), 1.77 (ddd, J = 12.8, 3.6 and 3.2 Hz, 1 H), 2.10 (dddq, J = 18.4, 6.4, 3.2 and 2.8 Hz, 1 H), 2.20–2.28 (m, 1 H), 2.35–2.43 (m, 2 H), 4.95 (s, 1H), 5.47 (brs, 1 H), 7.50 (d, J = 8.4 Hz, 2 H), 8.14 (d, J = 8.8 Hz, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 24.1, 24.4, 27.8, 28.4, 28.7, 33.9, 41.6, 74.0, 76.0, 123.3, 124.6, 126.8, 132.1, 147.0, 150.9; IR (KBr, Neat): 2934, 1600, 1520, 1346, 1229, 1077, 1057, 851, 707 cm^{-1}. HRMS (APCI) cald. for $C_{17}H_{21}NO_3$ $(M+H)^+$ requires 288.1599; found 288.1609.

4-(2-Nitrophenyl)-2,2,6-trimethyl-3-oxabicyclo[3.3.1]non-6-ene, 3f. Colourless (155 mg, 54%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.85 (m, 3 H), 1.33 (s, 3 H), 1.40 (s, 3 H), 1.59 (ddd, J = 6.4, 3.2, and 3.2 Hz, 1 H), 1.72 (ddd, J = 12.4, 3.2 and 2.8 Hz, 1 H), 2.11 (dddq, J = 18.8, 6.0, 3.2 and 2.8 Hz, 1 H), 2.36–2.50 (m, 3 H), 5.45–5.47 (m, 1 H), 5.49–5.52 (m, 1 H), 7.36 (t, J = 8.4 Hz, 1 H), 7.55 (t, J = 8.0 Hz, 1 H), 7.80 (d, J = 8.0 Hz, 1 H), 7.93 (d, J = 8.4 Hz, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 24.2, 24.3, 27.8, 28.2, 28.8, 33.9, 39.1, 70.1, 76.2, 124.2, 124.5, 127.6, 129.5, 132.4, 133.3, 138.3, 147.5; IR (KBr, Neat): 2933, 1525, 1345, 1228, 1067, 1055, 746, 709 cm^{-1}. HRMS (APCI) cald. for $C_{17}H_{21}NO_3$ (M^+) requires 287.1521; found 287.1528.

2,2,6-Trimethyl-4-naphthyl-3-oxabicyclo[3.3.1]non-6-ene, 3g. Colourless oil (161 mg, 55%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.79 (m, 3 H), 1.40 (s, 3 H), 1.42 (s, 3 H), 1.59 (ddd, J = 6.4, 3.6 and 2.8 Hz, 1 H), 1.76 (ddd, J = 12.0, 3.6 and 3.2 Hz, 1 H), 2.10 (dddq, J = 18.4, 6.4, 3.2 and 2.8 Hz, 1 H), 2.32–2.48 (m, 3 H), 5.03 (d, J = 1.2 Hz, 1 H), 5.46 (brs, 1 H), 7.38–7.45 (m, 3 H), 7.73–7.82 (m, 4 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 24.3, 24.4, 27.9, 28.7, 28.9, 34.2, 41.6, 74.6, 75.7, 123.6, 124.1, 124.7, 125.4, 125.8, 127.5, 127.7, 128.3, 132.8, 133.4, 133.5, 140.6; IR (KBr, Neat): 2931, 1461, 1368, 1284, 1126, 1097, 1078, 818, 776, 739 cm^{-1}. HRMS (APCI) cald. for $C_{21}H_{24}O$ (M^+) requires 292.1827; found 292.1818.

2,2,6-Trimethyl-4-styryl-3-oxabicyclo[3.3.1]non-6-ene, 3h. Colourless oil (166 mg, 62%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.29 (s, 3 H), 1.37 (s, 3 H), 164–1.68 (m, 1 H), 1.69 (s, 3 H), 1.70 (ddd, J = 12.0, 3.6 and 3.2 Hz, 1 H), 2.06–2.10 (m, 1 H), 2.11–2.16 (m, 1 H), 2.22–2.29 (m, 1 H), 2.35–2.44 (m, 1 H), 4.47 (d, J = 5.6 Hz, 1 H), 5.55–5.60 (m, 1 H), 6.16 (dd, J = 16.0 and 6.4 Hz, 1 H), 6.56 (d, J = 16.4 Hz, 1 H), 7.18–7.21 (m, 1 H), 7.27–7.32 (m,

2 H), 7.34–7.38 (m, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 24.3, 25.3, 27.9, 28.2, 28.8, 34.2, 40.7, 74.7, 75.6, 124.0, 126.6, 127.4, 128.6, 129.0, 131.4, 133.5, 137.4; IR (KBr, Neat): 2930, 1646, 1456, 1374, 1226, 1083, 1061, 968, 746, 694 cm^{-1}. HRMS (APCI) cald. for $C_{19}H_{24}O$ (M^+) requires 268.1827; found 268.1838.

2,2,6-Trimethyl-4[2-(4-nitrophenyl)-vinyl]-3-oxabicyclo[3.3.1]-non-6-ene, 3i. Colourless oil (172 mg, 55%) ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.30 (s, 3 H), 1.37 (s, 3 H), 1.56 (ddd, J = 5.6, 2.8 and 2.8 Hz, 1 H), 1.64 (s, 3 H), 1.73 (ddd, J = 12.4, 3.2 and 2.8 Hz, 1 H), 2.08–2.17 (m, 2 H), 2.23–2.29 (m, 1 H), 2.34–2.42 (m, 1 H), 4.51(d, J = 5.2 Hz, 1 H), 5.56 (brs, 1 H), 6.37 (dd, J = 16.0 and 5.6 Hz, 1 H), 6.64 (d, J = 16.0 Hz, 1 H), 7.48 (d, J = 8.8 Hz, 2 H), 8.15 (d, J = 8.8 Hz, 2 H), ^{13}C NMR (100 MHz, $CDCl_3$): δ 24.1, 25.0, 27.8, 28.1, 28.6, 34.0, 40.2, 73.7, 75.7, 124.0, 124.3, 126.5, 126.8, 132.7, 136.5, 143.9, 146.7; IR (KBr, Neat): 2930, 1596, 1518, 1341, 1083, 1050, 973, 858, 746 cm^{-1}. HRMS (APCI) cald. for $C_{19}H_{23}NO_3$ (M^+) requires 313.1678; found 313.1686.

4-(4,4,8-Trimethyl-3-oxabicyclo[3.3.1]non-7-en-2-yl)-benzoic acid methyl ester, 3j. Colourless oil (171 mg, 57%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.82 (m, 3 H), 1.34 (s, 3 H), 1.40 (s, 3 H), 1.57 (ddd, J = 6.4, 3.6 and 2.8 Hz, 1 H), 1.74 (ddd, J = 12.8, 3.2 and 2.8 Hz, 1 H), 2.08 (dddq, J = 18.8, 6.0, 3.2 and 2.8 Hz, 1 H), 2.22–2.29 (m, 1 H), 2.32–2.43 (m, 2 H), 3.89 (s, 3 H), 4.92 (s, 1 H), 5.44 (brs, 1 H), 7.40 (d, J = 8.0 Hz, 2 H), 7.95 (d, J = 8.4 Hz, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 24.1, 24.3, 27.8, 28.5, 28.8, 34.0, 41.6, 52.2, 74.3, 75.7, 124.0, 125.9, 128.6, 129.4, 132.8, 148.5, 167.4; IR (KBr, Neat): 2952, 1720, 1436, 1278, 1107, 1079, 1017, 768, 713 cm^{-1}. HRMS (APCI) cald. for $C_{19}H_{24}O_3$ $(M+H)^+$ requires 301.1803; found 301.1808.

4-(4,4,8-Trimethyl-3-oxabicyclo[3.3.1]-non-7-en-2-yl)-phenol, 3k. Colourless oil (156 mg, 60%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.91 (m, 3 H), 1.32 (s, 3 H), 1.38 (s, 3 H), 1.54 (ddd, J = 6.0, 3.2 and 2.8 Hz,1 H), 1.71 (ddd, J = 12.4, 3.2 and 2.8 Hz, 1 H), 2.08 (dddq, J = 18.8, 6.0, 3.2 and 2.8 Hz, 1 H), 2.12–2.17 (m, 1 H), 2.30–2.42 (m, 2 H), 4.91 (brs, 1 H), 5.27 (brs, 1 H), 5.44 (brs, 1 H), 6.73 (d, J = 8.4 Hz, 2 H), 7.17 (d, J = 8.0 Hz, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 24.1, 24.4, 27.8, 28.3, 28.8, 34.2, 41.7, 74.2, 75.7, 115.0, 123.4, 127.0, 133.4, 134.9, 154.6; IR (KBr, Neat): 3372, 2929, 1611, 1457, 1377, 1227, 1168, 1075, 1053, 828 cm^{-1}. HRMS (APCI) cald. for $C_{17}H_{22}O_2$ $(M+H)^+$ requires 259.1698; found 259.1701.

2,2,6-Trimethyl-4-*p*-tolyl-3-oxabicyclo[3.3.1]non-6-ene, 3l. Colourless oil (174 mg, 68%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.88 (m, 3 H), 1.32 (s, 3 H), 1.38 (s, 3 H), 1.54 (ddd, J = 6.0, 3.2 and 2.8 Hz, 1 H), 1.71 (ddd, J = 12.4, 3.2 and 3.2 Hz, 1 H), 2.08 (dddq, J = 18.4, 6.4, 3.6 and 2.8 Hz, 1 H), 2.14–2.19 (m, 1 H), 2.30 (s, 3 H), 2.30–2.42 (m, 2 H), 4.84 (brs, 1 H), 5.43 (brs, 1 H), 7.06 (d, J = 8.0 Hz, 2 H), 7.20 (d, J = 8.0 Hz, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.2, 24.1, 24.4, 27.8, 28.4, 28.8, 34.0, 41.6, 74.2, 75.3, 123.2, 125.6, 128.5, 133.4, 135.9, 140.0; IR (KBr, Neat): 2967, 2930, 1610, 1445, 1375, 1285, 1109, 1075, 1020, 806, 754 cm^{-1}. HRMS (APCI) cald. for $C_{18}H_{24}O$ (M^+) requires 256.1827; found 256.1827.

4-Cyclohexyl-2,2,6-trimethyl-3-oxabicyclo[3.3.1]non-6-ene, 3m. Colourless oil (154 mg, 62%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.70–1.00 (m, 4 H), 1.09–1.19 (m, 1 H), 1.20 (s, 3 H), 1.25 (s, 3 H), 1.46 (ddd, J = 6.0, 3.2 and 2.8 Hz, 1 H), 1.58–1.70 (m, 4 H), 1.74 (s, 3 H), 1.84–1.92 (m, 2 H), 2.00–2.19 (m, 4 H), 2.30–2.40 (m, 1 H), 3.25 (d, J = 10.0 Hz, 1 H), 5.53 (brs, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 24.2, 25.3, 25.8, 26.0, 26.9, 28.1, 28.7, 29.0, 29.5, 30.6, 34.4, 35.0, 40.1, 75.0, 76.9, 124.4, 133.7; IR (KBr, Neat): 2923, 2851, 1641, 1449, 1378, 1228, 1063, 1045, 880, 801 cm^{-1}. HRMS (APCI) cald. for $C_{17}H_{28}O$ (M^+) requires 248.2140; found 248.2144.

2,2,6-Trimethyl-4-ethyl-3-oxabicyclo[3.3.1]non-6-ene, 3n. Colourless oil (16 mg, 8%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.93 (t, J = 7.6 Hz, 3 H), 1.21 (s, 3 H), 1.28, (s, 3 H), 1.40 (quin, J = 7.2 Hz, 2 H), 1.48 (ddd, J = 5.6, 3.2 and 2.8 Hz, 1 H), 1.63 (ddd, J = 12.4, 2.8 and 2.8 Hz, 1 H), 1.73 (s, 3 H), 1.92–1.96 (m, 1 H), 2.06 (dddq, J = 18.8, 6.4, 2.8 and 2.8 Hz, 1 H), 2.09–2.14 (m, 1 H), 2.28–2.38 (m, 1 H), 3.56 (t, J = 6.8 Hz, 1 H), 5.51 (brs, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 11.1, 24.2, 25.4, 27.8, 28.0, 28.6, 28.9, 34.5, 38.1, 75.0, 75.6, 123.9, 133.7; IR (KBr, Neat): 2959, 2931, 1648, 1458, 1377, 1108, 1068, 1042, 866, 743 cm^{-1}. HRMS (APCI) cald. for $C_{13}H_{22}O$ (M^+) requires 194.1671; found 194.1677.

4-Propyl-2,2,6-trimethyl-3-oxabicyclo[3.3.1]non-6-ene, 3o. Colourless oil (17 mg, 8%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.90 (t, J = 6.8 Hz, 3 H), 1.20 (s, 3H), 1.24–1.44 (m, 4 H), 1.29, (s, 3 H), 1.47 (ddd, J = 6.0, 3.6 and 2.8 Hz, 1 H), 1.62 (ddd, J = 12.4, 3.2 and 3.2 Hz, 1 H), 1.73 (s, 3 H), 1.88–1.92 (m, 1 H), 2.05 (dddq, J = 18.8, 6.0, 3.2 and 2.8 Hz, 1 H), 2.10–2.16 (m, 1 H), 2.30–2.38 (m, 1 H), 3.68 (ddd, J = 7.6, 4.8 and 1.6 Hz, 1 H), 5.52 (brs, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 14.1, 19.7, 24.2, 25.4, 28.0, 28.7, 28.9, 34.5, 37.1, 38.5, 73.5, 74.9, 123.9, 133.7; IR (KBr, Neat): 2957, 2931, 1645, 1458, 1378, 1111, 1077, 886, 806 cm^{-1}. HRMS (APCI) cald. for $C_{14}H_{24}O$ (M^+) requires 208.1827; found 208.1824.

4-Isobutyl-2,2,6-trimethyl-3-oxabicyclo[3.3.1]non-6-ene, 3p. Colourless oil (22 mg, 10%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.87 (d, J = 6.4 Hz, 3 H), 0.89 (d, J = 6.8 Hz, 3 H), 1.08–1.16 (m, 1 H), 1.20 (s, 3H), 1.30 (s, 3 H), 1.34–1.41 (m, 1 H), 1.48 (ddd, J = 6.4, 3.2 and 3.2 Hz,1 H), 1.63 (ddd, J = 12.0, 3.6 and 3.2 Hz, 1 H), 1.74 (s, 3 H), 1.75–1.82 (m, 1 H), 1.83–1.88 (m, 1 H), 2.05 (dddq, J = 18.8, 6.4, 3.2 and 2.4 Hz, 1 H), 2.10–2.17 (m, 1 H), 2.29–2.37 (m, 1 H), 3.78 (ddd, J = 9.2, 4.4, and 2.8 Hz, 1 H), 5.51 (brs, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 22.0, 23.5, 24.1, 24.6, 25.5, 28.0, 28.8, 29.9, 34.4, 38.9, 43.9, 71.4, 74.9, 123.9, 133.8; IR (KBr, Neat): 2954, 2933, 1463, 1378, 1227, 1120, 1077, 1015, 892, 800 cm^{-1}. HRMS (APCI) cald. for $C_{15}H_{26}O$ (M^+) requires 222.1984; found 222.1986.

4-Hexyl-2,2,6-trimethyl-3-oxabicyclo[3.3.1]non-6-ene, 3q. Colourless oil (38 mg, 15%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.87 (t, J = 6.8 Hz, 3 H), 1.20 (s, 3 H), 1.22–1.32 (m, 10 H), 1.28 (s, 3 H), 1.47 (ddd, J = 6.4, 3.2 and 3.2 Hz, 1 H), 1.62 (ddd, J = 12.4, 3.2 and 2.8 Hz, 1 H), 1.73 (s, 3 H), 1.85–1.92 (m, 1 H), 2.05 (dddq, J = 19.2, 6.0, 3.2 and 2.8 Hz, 1 H), 2.10–2.14 (m, 1H) 2.28–2.40 (m, 1 H), 3.65 (t, J = 5.6 Hz, 1 H), 5.50 (brs, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 14.3, 22.8, 24.2, 25.4, 26.6, 28.1, 28.7, 28.9, 29.5, 32.1, 34.5, 35.1, 38.5, 73.9, 74.9, 123.9, 133.7; IR (KBr, Neat): 2929, 2868, 1647, 1458, 1377, 1077, 1017, 886, 724 cm^{-1}. HRMS (APCI) cald. for $C_{17}H_{30}O$ (M^+) requires 250.2297; found 250.2298.

4-Pentadecyl-2,2,6-trimethyl-3-oxabicyclo[3.3.1]non-6-ene, 3r. Semisolid (38 mg, 10%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.88 (t, J = 6.8 Hz, 3 H), 1.20 (s, 3 H), 1.21–1.28 (m, 20 H), 1.28 (s, 3 H), 1.30–1.49 (m, 5 H), 1.62 (ddd, J = 12.4, 3.2 and 3.2 Hz, 1 H), 1.73 (s, 3 H), 1.90–1.93 (m, 2 H), 2.00–2.15 (m, 4 H), 2.26–2.37 (m, 2 H), 3.65 (t, J = 5.6 Hz, 1 H), 5.51 (brs, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 14.3, 22.9, 24.2, 25.4, 26.6, 28.0, 28.7, 28.9, 29.85(5C), 29.9 (5C), 32.1, 34.5, 35.0, 38.4, 73.9, 74.9, 123.8, 133.7; IR (KBr, Neat): 2924, 2854, 1644, 1459, 1378, 1226, 1076, 1067, 801, 721 cm^{-1}. HRMS (APCI) cald. for $C_{26}H_{48}O$ (M^+) requires 376.3705; found 376.3696.

5-Isopropenyl-2-methyl-6-phenyl-2-vinyltetrahydropyran, 4a/5a (2 : 1). Colourless oil (61 mg, 25%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.25 (s, 1 H), 1.29 (s, 2 H), 1.39 (s, 2 H), 1.42 (s, 1 H), 1.62–1.74 (m, 2 H), 1.79–1.90 (m, 1 H), 1.96–2.02 (m, 1 H), 2.20–2.28 (m, 1 H), 4.44 (d, J = 10.4 Hz, 1 H), 4.52 (brs, 0.33 H), 4.55 (brs, 0.67 H), 4.59 (brs, 0.67 H), 4.65 (brs, 0.33 H), 4.99 (d, J = 10.8 Hz, 0.33 H), 5.07 (d, J = 14.4 Hz, 0.33 H), 5.22 (dd, J = 18.0 and 1.2 Hz, 0.67 H), 5.29 (dd, J = 11.2 and 1.2 Hz, 0.67 H), 5.89 (dd, J = 18.0 and 12.0 Hz, 0.67 H), 5.99 (dd, J = 17.2 and 10.8 Hz, 0.33 H), 7.22–7.26 (m, 2 H), 7.28–7.31 (m, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.6, 27.1, 31.4, 34.6, 50.8, 75.8, 78.5, 112.1, 115.3, 127.7, 128.1, 128.2, 141.8, 143.1, 146.7 (major, **4a**); IR (KBr, Neat): 2967, 2930, 1643, 1450, 1370, 1116, 1050, 889, 759, 698 cm^{-1}. HRMS (APCI) cald. for $C_{17}H_{22}O$ (M+H)$^+$ requires 243.1749; found 243.1760.

5-Isopropenyl-2-methyl-6-(4-nitrophenyl)-2-vinyl-tetrahydropyran, 4e. Colourless oil (43 mg, 15%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.31 (s, 3 H), 1.42 (s, 3 H), 1.54–1.78 (m, 2 H), 1.80–1.92 (m, 1 H), 2.00–2.05 (m, 1 H), 2.11–2.19 (m, 1 H), 4.53 (brs, 1 H), 4.56 (d, J = 10.0 Hz, 1 H), 4.63 (brs, 1 H), 5.22 (d, J = 17.6 Hz, 1 H), 5.32 (d, J = 11.2 Hz, 1 H), 5.86 (dd, J = 18.0 and 11.2 Hz, 1 H), 7.47 (d, J = 8.4 Hz, 2 H), 8.15 (d, J = 8.0 Hz, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 21.6, 26.8, 31.2, 34.4, 51.4, 76.1, 77.4, 113.1, 115.8, 123.4, 128.4, 142.4, 145.5, 147.6, 149.3; IR (KBr, Neat): 2928, 2857, 1606, 1520, 1346, 1262, 1108, 1055, 894, 751, 696 cm^{-1}. HRMS (APCI) cald. for $C_{17}H_{21}NO_3$ (M+H)$^+$ requires 288.1599; found 288.1605.

6-Ethyl-5-isopropenyl-2-methyl-2-vinyltetrahydropyran, 4n/5n (3 : 1). Colourless oil (126 mg, 65%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.91 (t, J = 7.2 Hz, 0.75 H), 0.94 (t, J = 7.2 Hz, 2.25 H), 1.23 (s, 3 H), 1.24–1.30 (m, 2 H), 1.47–1.57 (m, 2 H), 1.62 (s, 3 H), 1.61–1.65 (m, 1 H), 1.66–1.71 (m, 1 H), 1.85–1.94 (m, 1 H), 3.36–3.42 (m, 0.75 H), 3.45–3.51 (m, 0.25 H), 4.70 (brs, 1.50 H), 4.75 (brs, 0.50 H), 4.99 (dd, J = 11.2 and 1.6 Hz, 0.25 H), 5.13 (dd, J = 18.0 and 1.6 Hz, 0.75 H), 5.19 (dd, J = 10.8 and 1.2 Hz, 0.75 H), 5.22 (dd, J = 17.6 and 1.6 Hz, 0.25 H), 5.76 (dd, J = 17.6 and 10.8 Hz, 0.75 H), 5.93 (dd, J = 17.6 and 11.2 Hz, 0.25 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 10.2, 20.3, 26.6, 27.0, 31.4, 34.6, 49.7, 74.8, 75.0, 111.7, 114.8, 143.5, 147.6 (major, **4n**); IR (KBr, Neat): 2928, 2873, 1641, 1458, 1377, 1116, 995, 888, 740 cm^{-1}. HRMS (APCI) cald. for $C_{13}H_{22}O$ (M+H)$^+$ requires 195.1749; found 195.1747.

6-Propyl-5-isopropenyl-2-methyl-2-vinyltetrahydropyran, 4o/5o (3 : 1). Colourless oil (135 mg, 65%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.87 (t, J = 7.6 Hz, 0.75 H), 0.88 (t, J = 7.2 Hz, 2.25 H), 1.20 (s, 0.75 H), 1.21 (s, 2.25 H), 1.23–1.35 (m, 4 H), 1.36–1.43 (m, 1 H), 1.45–1.60 (m, 2 H), 1.62 (s, 2.25 H), 1.64 (s, 0.75 H), 1.67–1.71 (m, 1 H), 1.85–1.92 (m, 1 H), 3.46 (dt, J = 9.2 and 2.0 Hz, 0.75 H), 3.56 (dt, J = 10.0 and 2.4 Hz, 0.25 H), 4.70 (brs, 1.50 H), 4.75 (brs, 0.50 H), 4.98 (dd, J = 10.8 and 1.6 Hz, 0.25 H), 5.12 (dd, J = 17.6 and 1.6 Hz, 0.75 H), 5.19 (dd, J = 11.2 and 1.2 Hz, 0.75 H), 5.20 (dd, J = 16.4 and 1.6 Hz, 0.25 H), 5.76 (dd, J = 18.0 and 12.2 Hz, 0.75 H), 5.92 (dd, J = 17.2 and 10.4 Hz, 0.25 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 14.2, 18.8, 20.3, 27.0, 31.4, 34.5, 35.9, 50.1, 73.4, 74.8, 111.7, 114.7, 143.5, 147.6 (major, **4o**); IR (KBr, Neat): 2957, 2931, 1643, 1452, 1377, 1114, 1067, 1026, 916, 889, 746 cm^{-1}. HRMS (APCI) cald. for $C_{14}H_{24}O$ (M+H)$^+$ requires 209.1905; found 209.1914.

6-Isobutyl-5-isopropenyl-2-methyl-2-vinyltetrahydro-pyran, 4p/5p (3 : 1). Colourless oil (149 mg, 67%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.83 (d, J = 6.8 Hz, 3 H), 0.89 (d, J = 6.8 Hz, 3 H), 1.11–1.18 (m, 2 H), 1.21 (s, 3 H), 1.23–1.31 (m, 2 H), 1.48–1.58 (m, 1 H), 1.61 (s, 3 H), 1.65–1.71 (m, 1 H), 1.83–1.92 (m, 2 H), 3.50 (dt, J = 10.4 and 2.0 Hz, 0.75 H), 3.62 (dt, J = 10.0 and 2.0 Hz, 0.25 H), 4.69 (brs, 1.50 H), 4.73 (brs, 0.50 H), 4.98 (dd, J = 10.8 and 2.0 Hz, 0.25 H), 5.12 (dd, J = 17.6 and 1.2 Hz, 0.75 H), 5.18 (dd, J = 8.0 and 1.6 Hz, 0.25 H), 5.21 (dd, J = 11.2 and 1.2 Hz, 0.75 H), 5.79 (dd, J = 18.0 and 11.2 Hz, 0.75 H), 5.92 (dd, J = 17.2 and 10.8 Hz, 0.25 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.1, 21.5, 23.9, 24.2, 27.0, 31.4, 34.2, 43.1, 50.6, 71.7, 74.7, 111.8, 114.8, 143.6, 147.6 (major, **4p**); IR (KBr, Neat): 2950, 2932, 1643, 1450, 1380, 1264, 1118, 1068, 997, 918, 890, 735 cm^{-1}. HRMS (APCI) cald. for $C_{15}H_{26}O$ (M+H)$^+$ requires 223.2062.; found 223.2063.

6-Hexyl-5-isopropenyl-2-methyl-2-vinyltetrahydropyran, 4q/5q (3 : 1). Colourless oil (150 mg, 60%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.86 (t, J = 6.8 Hz, 3 H), 1.22 (s, 3 H), 1.23–1.34 (m, 10 H), 1.40–1.57 (m, 2 H), 1.62 (s, 3 H), 1.64–1.71 (m, 1 H), 1.85–1.91 (m, 2 H), 3.45 (t, J = 9.6 Hz, 0.75 H), 3.54 (t, J = 8.0 Hz, 0.25 H), 4.70 (brs, 1.50 H), 4.73 (brs, 0.50 H), 4.98 (dd, J = 10.8 and 1.2 Hz, 0.25 H), 5.12 (dd, J = 17.6 and 1.2 Hz, 0.75 H), 5.19 (dd, J = 11.2 and 1.6 Hz, 0.75 H), 5.20 (dd, J = 14.0 and 1.2 Hz, 0.25 H), 5.76 (dd, J = 18.0 and 11.2 Hz, 0.75 H), 5.93 (dd, J = 17.6 and 10.8 Hz, 0.25 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 14.3, 20.3, 22.9, 25.8, 27.1, 29.6, 31.4, 32.2, 33.9, 34.6, 50.1, 73.7, 74.8, 111.7, 114.7, 143.6, 147.7 (major, **4q**); IR (KBr, Neat): 2929, 2858, 1643, 1454, 1378, 1117, 1074, 916, 889 cm^{-1}. HRMS (APCI) cald. for $C_{17}H_{30}O$ (M+H)$^+$ requires 251.2375; found 251.2380.

5-Isopropenyl-2-methyl-6-pentadecyl-2-vinyltetrahydro-pyran, 4r/5r (3 : 1). Colourless oil (233 mg, 62%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.88 (t, J = 7.2 Hz, 3 H), 1.21 (s, 3 H), 1.22–1.30 (m, 24 H), 1.40–1.57 (m, 5 H), 1.62 (s, 2.25 H), 1.64 (s, 0.75 H), 1.66–1.71 (m, 2 H), 1.84–1.92 (m, 2 H), 3.42–3.47 (m, 0.75 H), 3.50–3.54 (m, 0.25 H), 4.70 (brs, 1.50 H), 4.74 (brs, 0.50 H), 4.98 (dd, J = 10.4 and 1.6 Hz, 0.25 H), 5.12 (dd, J = 18.0 and 1.2 Hz, 0.75 H), 5.19 (dd, J = 11.2 and 1.2 Hz, 0.75 H), 5.21 (dd, J = 16.0 and 1.6 Hz, 0.25 H), 5.76 (dd, J = 18.0 and 11.2 Hz, 0.75 H), 5.93 (dd, J = 17.6 and 10.8 Hz, 0.25 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 14.3, 20.3, 22.9, 25.8, 27.1, 29.6, 29.9 (9C), 31.4, 32.2, 33.9, 34.6, 50.2, 73.7, 74.8, 111.7, 114.7, 143.6, 147.7 (major, **4r**); IR (KBr, Neat): 2923, 2855, 1643, 1455, 1377, 1118, 1077, 889, 721, 683 cm^{-1}. HRMS (APCI) cald. for $C_{26}H_{48}O$ (M^+) requires 376.3705; found 376.3705.

Tetracyclic compound 15. Colourless oil (103 mg, 40%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.22 (s, 3 H), 1.39 (dddd, J = 4.4, 3.6, 3.6 and 3.6 Hz, 1 H), 1.42 (s, 3 H), 1.52 (d, J = 1.2 Hz, 3 H), 1.53–1.59 (m, 2 H), 1.80–1.84 (m, 1 H), 1.87 (ddd, J = 13.6, 3.2

and 2.8 Hz, 1 H), 2.06 (ddddd, J = 13.0, 5.2, 3.6, 3.2 and 2.8 Hz, 1 H), 2.33 (dddd, J = 13.6, 3.2, 3.2 and 2.8 Hz, 1 H), 2.63 (brddd, J = 14.8, 7.6, 5.6 and 3.6 Hz,1 H), 4.62 (d, J = 2.4 Hz, 1 H), 6.80 (d, J = 8.0 Hz, 1 H), 6.85 (td, J = 7.2 and 1.2, 1 H), 7.15–7.21 (m, J = 7.6 Hz, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 24.4, 26.2, 26.7, 26.9, 28.5, 32.4, 34.8, 36.7, 66.7, 74.9, 77.7, 117.0, 119.9, 122.2, 129.8, 130.6, 153.4; IR (KBr, Neat): 2961, 2934, 1611, 1484, 1366, 1247, 1107, 1094, 1049, 933, 753 cm^{-1}. HRMS (APCI) cald. for $C_{17}H_{22}O_2$ (M^+) requires 258.1620; found 258.1621.

6-Benzyl-5-isopropyl-2-methyl-2-vinyltetrahydropyran 18c/19c (3 : 2). Colourless oil (133 mg, 52%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.01 (s, 1.8 H), 1.18 (s, 1.2 H), 1.27 (s, 1.8 H), 1.32 (s, 1.2 H), 1.37–1.47 (m, 2 H), 1.59–1.78 (m, 2 H), 1.90–2.00 (m, 1 H), 2.76–2.84 (m, 1 H), 3.02 (dd, J = 16 and 5.6 Hz, 1 H), 3.87–3.99 (m, 1 H), 4.98–5.26 (m, 4 H), 5.83 (dd, J = 18.0 and 10.8 Hz, 0.6 H), 5.97 (dd, J = 17.6 and 10.8 Hz, 0.4 H), 7.03–7.11 (m, 3 H), 7.13–7.19 (m, 1 H), 7.30–7.34 (m, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.5, 20.6, 27.7, 27.8, 28.5, 31.3, 35.4, 37.9, 38.2, 38.4, 47.2, 47.4, 66.9, 67.9, 73.0, 74.5, 111.4, 114.9, 125.8, 125.9, 126.3, 126.7, 128.4, 128.9, 129.2, 129.3, 133.6, 133.7, 143.0, 145.8, 145.9, 146.4; IR (KBr, Neat): 2967, 2934, 1643, 1448, 1382, 1117, 1076, 1037, 921, 759, 729 cm^{-1}. HRMS (APCI) cald. for $C_{18}H_{24}O$ $(M+H)^+$ requires 257.1905; found 257.1914.

6-(3-Benzyloxy-1-methylpropyl)-5-isopropenyl-2-methyl-2-vinyltetrahydropyran 18d/19d (2 : 1). Colourless oil (157 mg, 48%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.85 (d, J = 6.4 Hz, 2 H), 0.97 (d, J = 6.4 Hz, 1 H), 1.15 (s, 2 H), 1.20 (s, 1 H), 1.23 (s, 1 H), 1.26 (s, 2 H), 1.33–1.53 (m, 2 H), 1.62–1.76 (m, 2 H), 1.80–1.88 (m, 1 H), 2.00–2.16 (m, 1 H), 3.38–3.57 (m, 3 H), 4.48 (s, 0.66 H), 4.56 (s, 1.34 H), 4.70–4.75 (m, 2 H), 4.91–5.20 (m, 4 H), 5.67–5.76 (m, 0.67 H), 5.87 (dd, J = 17.6 and 10.8 Hz, 0.33 H), 7.32–7.37 (m, 5 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 12.6, 19.8, 27.1, 29.9, 31.1, 31.2, 34.4, 46.8, 69.1, 72.3, 73.1, 75.2, 111.8, 114.7, 127.8, 128.0, 128.5, 128.6, 138.5, 143.8 (major, **18d**); IR (KBr, Neat): 2928, 2862, 1639, 1448, 1264, 1080, 1050, 1027, 795, 738 cm^{-1}. HRMS (APCI) cald. for $C_{22}H_{32}O_2$ $(M+H)^+$ requires 329.2480; found 329.2491.

5 - Isopropenyl - 6 - [2 - (4 - methoxyphenyl) - ethyl] - 2 - methyl-2-vinyltetrahydropyran 18e/19e (2 : 1). Colourless oil (135 mg, 45%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.24 (s, 2 H), 1.25 (s, 1 H), 1.55 (brs, 3 H), 1.48–1.80 (m, 5 H), 1.86–1.96 (m, 2 H), 2.47–2.60 (m, 1 H), 2.73–2.87(m, 1 H), 3.41–3.52 (m, 1 H), 3.78 (brs, 3H), 4.56–4.71 (m, 2 H), 5.00 (dd, J = 10.8 and 1.6 Hz, 0.33 H), 5.11 (dd, J = 18.0 and 1.2 Hz, 0.67 H), 5.17 (dd, J = 11.2 and 1.2 Hz, 0.67 H), 5.24 (dd, J = 17.6 and 1.6 Hz, 0.33 H), 5.76 (dd, J = 18.0 and 11.2 Hz, 0.67 H), 5.96 (dd, J = 17.6 and 10.8 Hz, 0.33 H), 6.80 (d, J = 8.8 Hz, 2 H), 7.10 (d, J = 8.8 Hz, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.2, 20.9, 22.5, 22.9, 26.3, 26.9, 29.6, 29.9, 30.8, 31.0, 31.3, 34.5, 34.9, 35.8, 40.0, 50.1, 55.5, 71.1, 73.0, 75.0, 110.4, 111.0, 111.9, 113.8, 114.0, 114.8, 124.6, 126.7, 128.4, 129.6, 129.7, 133.6, 135.1, 143.5, 146.7, 147.5; IR (KBr, Neat): 2929, 2857, 1633, 1454, 1246, 1078, 1039, 888, 827 cm^{-1}. HRMS (APCI) cald. for $C_{20}H_{28}O_2$ $(M+H)^+$ requires 301.2167; found 301.2168.

6-(4-Chlorobenzyl)-5-isopropenyl-2-methyl-2-vinyl-tetrahydropyran 18f/19f (3 : 2). Colourless oil (139 mg, 48%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.07 (s, 1.80 H), 1.17 (s, 1.20 H), 1.27 (s, 1.80 H), 1.33 (s, 1.20 H), 1.35–1.43 (m 1 H), 1.54–1.77 (m, 3 H), 1.96–2.04 (m, 1 H), 2.61–2.80 (m, 1 H), 2.98 (dd, J = 16.0 and 5.6 Hz, 1 H), 3.83–3.96 (m, 1 H), 4.91–5.10 (m, 1 H), 5.14–5.26 (m, 3 H), 5.83 (dd, J = 17.6 and 11.2 Hz, 0.60 H), 5.96 (dd, J = 17.6 and 10.8 Hz, 0.40 H), 6.96–7.0 (m, 1 H), 7.04–7.08 (m, 1 H), 7.23–7.32 (m, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.5, 20.6, 27.7, 28.4, 31.2, 35.3, 35.4, 37.3, 37.6, 38.7, 46.9, 47.1, 66.7, 67.8, 73.2, 74.6, 74.8, 111.6, 115.0, 124.5, 126.1, 126.2, 126.8, 128.3, 130.6, 130.7, 132.0, 132.2 143.0, 146.3, 147.9; IR (KBr, Neat): 2968, 2929, 2872, 1633, 1467, 1369, 1227, 1116, 1077, 922, 881, 814, 802 cm^{-1}. HRMS (APCI) cald. for $C_{18}H_{23}ClO$ $(M+H)^+$ requires 291.1515; found 291.1519.

6-(4-Bromobenzyl)-5-isopropenyl-2-methyl-2-vinyl-tetrahydropyran 18g/19g (3 : 2). Colourless oil (160 mg, 48%); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.07 (s, 1.80 H), 1.17 (s, 1.20 H), 1.27 (s, 1.80 H), 1.33 (s, 1.20 H), 1.35–1.42 (m, 1 H), 1.56–1.76 (m, 3 H), 1.94–2.0 (m, 1 H), 2.60–2.78 (m, 1 H), 2.98 (dd, J = 16.0 and 5.6 Hz, 1 H), 3.80–3.98 (m, 1 H), 5.04 (dd, J = 10.8 and 1.2 Hz, 1H), 5.14–5.28 (m, 3 H), 5.83 (dd, J = 17.6 and 11.2 Hz, 0.60 H), 5.96 (dd, J = 17.6 and 10.8 Hz, 0.40 H), 6.90–6.95 (m, 1 H), 7.18–7.23 (m, 1 H), 7.43 (dd, J = 8.4 and 2.0 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 20.4, 20.5, 27.7, 28.4, 31.2, 35.3, 35.4, 37.3, 37.6, 38.7, 46.8, 47.0, 66.6, 67.7, 73.1, 74.6, 111.6, 115.0, 120.0, 129.0, 129.8, 130.9, 131.0, 132.7, 143.0, 146.2, 148.3; IR (KBr, Neat): 2969, 2932, 2872, 1632, 1465, 1367, 1225, 1120, 1083, 923, 881, 814, 800 cm^{-1}. HRMS (APCI) cald. for $C_{18}H_{23}BrO$ $(M+H)^+$ requires 335.1010; found 335.1012.

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