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Aluminium Triflate Catalysed Cyclisation of Unsaturated Alcohols: Novel Synthesis of Rose Oxide and Analogues

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Aluminium trifluoromethanesulfonate was used as an efficient catalyst for the cycloisomerisation of several unsaturated alcohols into cyclic ethers such as rose oxide and some of its ether analogues.

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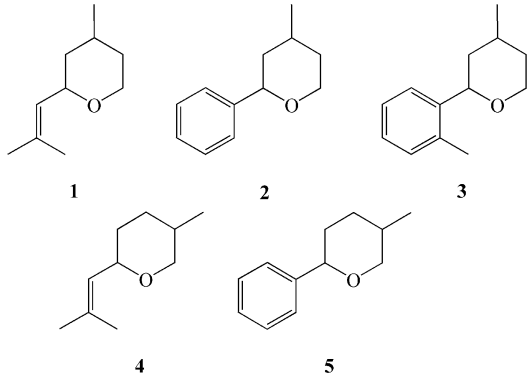
Introduction

Cyclic ethers are important structures frequently found in polyether antibiotics and other biologically active natural products, and great interest is focused on the development of new and efficient methods for the synthesis of cyclic ethers.[1] One of the most appealing approaches for the synthesis of these heterocycles is the direct intramolecular hydroalkoxylation, in which the cyclic ether is formed by addition of an alcohol to a nonactivated C=C bond.[2] These atom-economic processes, known to be catalysed by Brønsted acids in super-stoichiometric amounts, have been recently reported by the use of strong Lewis acids in catalytic amounts.[3] Thus, Sn^{IV}[4] and Al^{III}[5] triflates as well as Pt^{II}/PR_3,[6] Fe^{III}[7] and Au derivatives[8] have shown interesting catalytic activities in the formation of cyclic ethers from nonactivated olefins. The high activity of the metallic triflate catalysts is due to the strongly electron-withdrawing trifluoromethanesulfonate group.[9]

Pursuing the development of the cycloisomerisation of unsaturated alcohols involving the use of metallic trifluoromethanesulfonates as Lewis "superacid" catalysts,[10] we describe here some novel examples of this catalytic methodology applied to the synthesis of racemic cyclic ethers of the rose oxide family, such as compounds **1**–**5** (Scheme 1).

Rose oxide (**1**), first isolated from Bulgarian rose oil in 1959, is known to be the responsible component for the floral and green top notes of rose odorants.[11] This cyclic ether is present in its different isomeric forms and has been further identified in many plants, flowers and fruits such as *Eucalyptus citriodora*, geranium and tropical fruits.[12] It is used as a fragrance ingredient for the preparation of many perfuming compositions as well as perfumed goods.



Scheme 1.

Several synthetic procedures for the preparation of **1** have been described, and in almost all cases, citronellol is used as the starting material.[11b,13] The synthetic pathways generally involve the oxidation (including bromination) of the double bond of citronellol followed by elimination to a diene structure and further acid-catalysed cyclisation. However, this procedure lacks selectivity, because several isomeric byproducts are produced at the different steps.

In order to improve the olfactory properties of rose oxide, Firmenich reported in 1993 the synthesis of 4-methyl-2-phenyltetrahydropyran **2** (Doremox®), in which the isobutenyl moiety of **1** was substituted by a phenyl group.[14] This substitution increased the substantivity of rose scent,[15] that is, the persistence of the perfume material on blotters or skins.

Results and Discussion

Preparation of Unsaturated Alcohols

The Lewis acid cyclisation for the preparation of pyranyl ethers **1**–**5** requires the preparation of alcohols **6**, as shown

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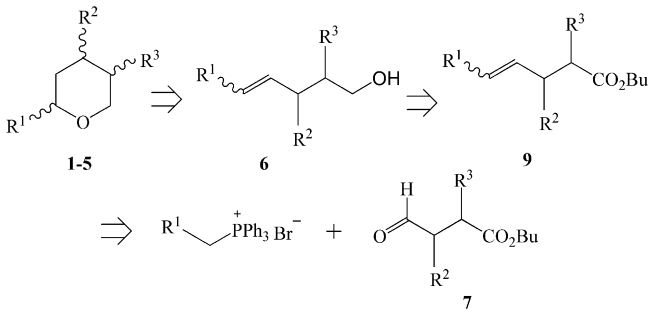
in Scheme 2. The unsaturated alcohols were prepared in three steps via intermediate γ-aldehyde–esters **7**.



Scheme 2.

Compounds **7a** and **7b** were obtained from butyl 2- and butyl 3-methyl-4-pentenoate by its olefin oxidative cleavage in the presence of $NaIO_4$ and a catalytic amount of ruthenium(III) chloride in 79 and 70% yield, respectively (Scheme 3).[16,17]

The reaction of **7a**,**b** with phosphonium salts **8a**–**c** afforded unsaturated esters **9a**–**e** in 66–79% isolated yield (Scheme 3, Table 1). Esters **9** were obtained in *Z*/*E* ratios ranging from 14:86 to 45:55. Further reduction of the ester functionality of **9** in the presence of lithium aluminium hydride afforded desired alcohols **6** in almost quantitative isolated yields and the same *Z*/*E* ratios.

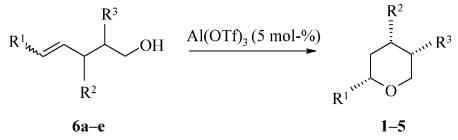
Table 1. Yields and *Z*/*E* ratios for esters **9a**–**e** and unsaturated alcohols **6a**–**e**.

Entry	R^1	R^2	R^3	Ester **9a**–**e** Yield [%]	*Z*/*E*	Alcohols **6a**–**e** Yield [%]	*Z*/*E*
1	$(CH_3)_2C{=}CH$	Me	H	**9a**, 70	28:72	**6a**, 87	28:72
2	Ph	Me	H	**9b**, 79	15:85	**6b**, 92	15:85
3	*ortho*-tolyl	Me	H	**9c**, 66	14:86	**6c**, 94	14:86
4	$(CH_3)_2C{=}CH$	H	Me	**9d**, 71	45:55	**6d**, 83	45:55
5	Ph	H	Me	**9e**, 71	30:70	**6e**, 78	30:70

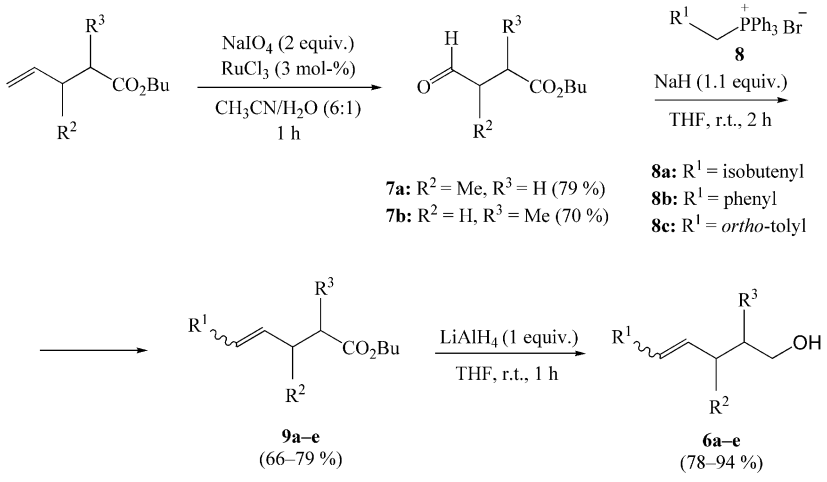
$Al(OTf)_3$-Catalysed Cycloisomerisation of Alcohols 6a–e

$Al(OTf)_3$ was shown to be an efficient catalyst for the cycloisomerisation of nonactivated unsaturated alcohols,

Table 2. $Al(OTf)_3$-catalysed cycloisomerisation of alcohols **6a**–**e**.



Entry	Unsaturated alcohol **6** (*Z*/*E*)	Conditions	Cyclic ethers	% Isolated yield (*cis*/*trans*)
1	**6a** (28:72)	CH_2Cl_2, reflux, 1 h	**1**	70 (82:18)
2	**6b** (15:85)	$ClCH_2CH_2Cl$, reflux, 3 h	**2**	85 (90:10)
3	**6b** (0:100)	$ClCH_2CH_2Cl$, reflux, 3 h	**2**	60 (95:5)
4	**6b** (28:72)	$ClCH_2CH_2Cl$, reflux, 3 h	**2**	86 (90:10)
5	**6c** (14:86)	$ClCH_2CH_2Cl$, reflux, 3 h	**3**	86 (92:8)
6	**6d** (45:55)	CH_2Cl_2, reflux, 2 h	**4**	77 (90:10)
7	**6e** (30:70)	$ClCH_2CH_2Cl$, reflux, 3 h	**5**	84 (86:14)



Scheme 3.

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leading quantitatively and regioselectively to the corresponding cyclic ethers.[5] This catalytic Lewis "superacid" system was used for the cyclisation of unsaturated alcohols **6a**–**e**. The cycloisomerisation was run in the presence of Al(OTf)$_3$ (5 mol-%) and led to the synthesis of rose oxide (**1**) and its analogues **2**–**5**, as illustrated in Table 2.

The cyclisation of alcohol **6a** (*Z*/*E* = 28:72) in refluxing CH_2Cl_2 afforded rose oxide (**1**) in 70% yield with a *cis*/*trans* ratio of 82:18 after 1 h (Table 2, Entry 1). The diastereoisomeric *cis*/*trans* ratio was determined by NOESY-NMR experiments. The major *cis* isomer is known to present the most powerful odorant properties.[13e] The cyclisation was regioselective and no formation of five- or seven-membered ring ethers was observed. Only the six-membered ring ether was formed; the intramolecular hydroalkoxylation of **6a** occurred exclusively at the internal position of the diene, on the less-substituted double bond. This regioselectivity can be explained by a carbocationic-type mechanism as discussed hereafter.

In order to prepare aryl substitutes oxane rings **2** and **3**, the cyclisation of alcohols **6b** and **6c** was carried out in refluxing dichloroethane. The cyclisation was also completely regioselective, leading exclusively to the corresponding six-membered ring ethers **2** and **3** in isolated yields of 60–86% (Table 2, Entries 2–5). The observed regioselectivities can be explained by the stabilisation of a benzylic-type cation intermediate formed in the presence of the metal triflate. Concerning the stereoselectivity of the cyclisation leading to **2** and **3**, the *cis* isomers were formed as the major products with 90–95% selectivities. The cyclisation of regioisomerically pure (*E*)-**6b** afforded **2** as a mixture of *cis* and *trans* isomers in a 95:5 ratio and 60% yield (Table 2, Entry 3). This *cis*/*trans* ratio was very similar to that of 90:10 obtained for **6b** with *Z*/*E* of 15:85 or 28:72 (Table 2, Entries 2 and 4), suggesting that the cyclisation could take place through a common carbocationic intermediate. The diastereoisomeric *cis*/*trans* ratio of the cyclic ethers was mainly dependent on stereochemical requirements of the intermediates and not on the *Z*/*E* ratios of starting alcohols **6**.

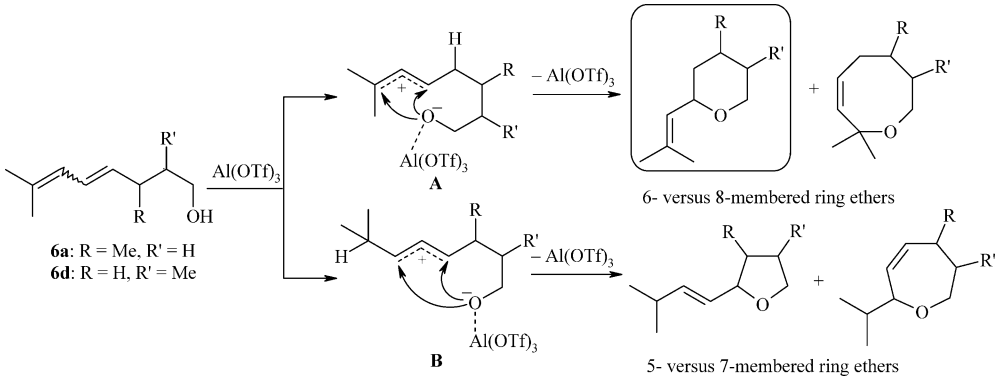
The Al(OTf)$_3$-catalysed cyclisation of **6d** (*Z*/*E* mixture of 45:55) afforded regiospecifically oxane **4** in 77% yield, with a *cis*/*trans* ratio of 90:10 (Table 2, Entry 6). The expected six-membered ring ether **5** was obtained from **6e** in 84% yield and with a *cis*/*trans* ratio of 86:14 (Table 2, Entry 7).

Mechanistic Considerations

Concerning the regiochemical outcome of the cyclisation, for example, the formation of five- vs. six-membered ring ethers with dienic alcohols **6a** and **6d**, the experimental results revealed that the cyclisation led exclusively to the corresponding oxanes **1** and **4**, respectively. The mechanism of the reaction can be explained by a first coordination of Al^{3+} to the hydroxy group of the alcohols leading to an increased acidity of the proton of the OH group, according to the results of theoretical calculations.[5] Proton addition to the diene unit may afford the formation of cationic allyl intermediates of type **A** or **B** (Scheme 4). Alkoxide addition can then either occur onto intermediate **A** to afford the formation of six- vs. eight-membered ring ethers. Alkoxide addition onto intermediate **B** should lead to five- and/or seven-membered ring ethers. The cyclisation towards tetrahydrofuran and tetrahydropyran derivatives should be more favourable than seven- and eight-membered ring ethers. This experimental regiospecificity can be explained by the selective formation of the π-allyl carbocation type intermediate **A**, which is more stable than **B** as a result of the higher substitution by the presence of the *gem*-dimethyl groups.

Cyclisation of alcohols **6b**, **6c** and **6e** was regiospecific and afforded exclusively the corresponding oxanes **2**, **3** and **5**, respectively. Here as well, the regioselectivity can be explained by the formation of a carbocation-type intermediate after the coordination of Al^{3+} to the hydroxy oxygen atom and the specific proton transfer from the OH group. The proton transfer occurs only on the carbon atom at the β-position of the phenyl group to form a stabilised carbocationic intermediate.

From a stereochemical point of view, the Al(OTf)$_3$-catalysed cycloisomerisation of differently 2- or 3-substituted alcohols **6a**–**e** formed the *cis* isomers of cyclic ethers **1**–**5** as the main products. For 3-methyl-substituted alcohols **6a**–**c**, the cyclisation led to the thermodynamically more stable *cis*-1,3-diequatorial stereoisomer.



Scheme 4.

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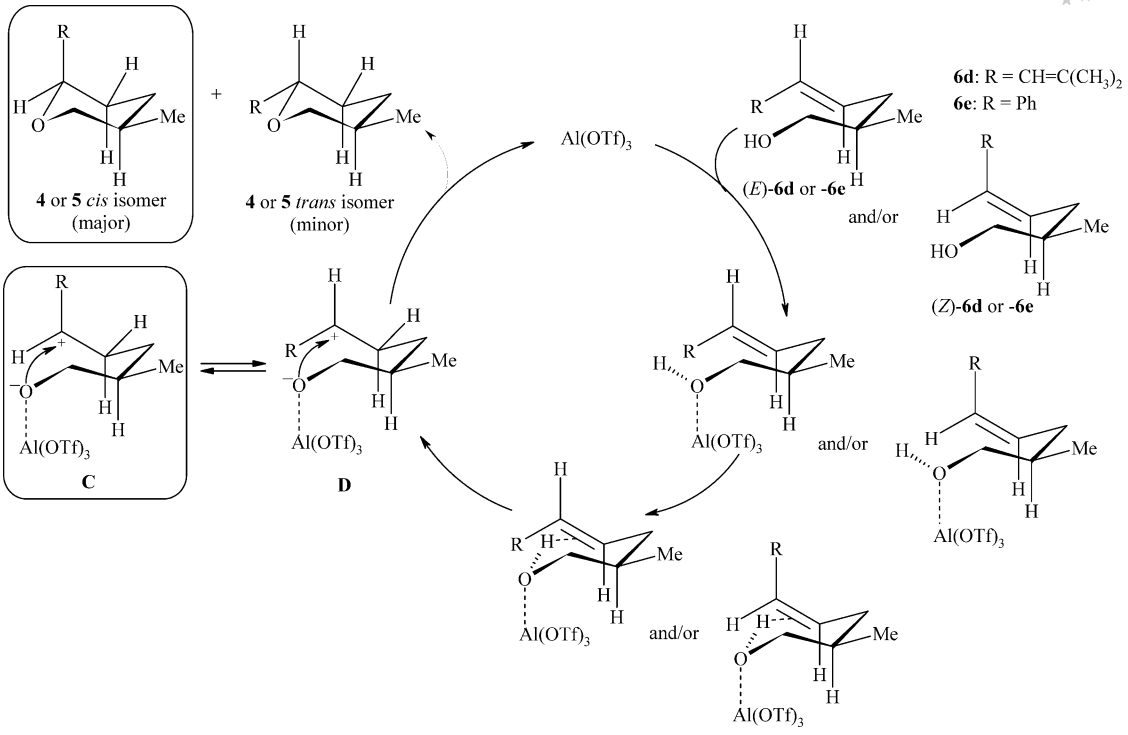

Scheme 5.

For the 2-methyl-substituted alcohols **6d** and **6e**, the mechanism of the cyclisation is proposed in Scheme 5. A first coordination of $Al(OTf)_3$ to the hydroxy group, which activates the proton transfer to the double bond, may afford the formation of two carbocation-type intermediates **C** and **D** in equilibrium as a result of the free rotation across the CH_2–CH^+ bond. In the more-stable chair-like conformation, carbocation **C** is sterically less hindered than **D** towards alkoxide addition. According to simple calculations,[18] carbocation **C** is slightly more stable than **D**, mainly affording the *cis*-1-axial-4-equatorial isomers **4** [R = $CH=C(CH_3)_2$] and **5** (R = Ph) by kinetic control with *cis*/*trans* ratios of 90:10 and 86:14, respectively.

Olfactory Evaluation of Cyclic Ethers 1–5

The olfactory properties for cyclic ethers **1**–**5** were evaluated to examine the influence of the different methyl substituents (Table 3).[19] Whereas **1** and **2** presented the expected characteristics of strong floral and green notes already as reported for rose oxide[11] and Doremox®,[14,20] ether **3** was analysed as weak and with a liquorice note. Ethers **4** and **5**, analogues of **1** and **2** by changing the position of the methyl group in the tetrahydropyran cycle, presented interesting notes: **4** was evaluated with anise, spearmint and rose oxide notes, whereas **5** presented creamy, vanilla, exotic fruits and citral notes.

Table 3. Olfactory properties of cyclic ethers **1**–**5** of *cis*/*trans* mixtures as obtained in Table 2.

Cyclic ethers	Olfactory properties
1	floral, green, herbal
2	rose oxide, green
3	liquorice, weak
4	anise, spearmint, rose oxide
5	creamy, vanilla, exotic fruits, citral

Conclusion

In conclusion, we present a novel and modulable selective synthesis of cyclic ethers of the rose oxide family in four steps and in high yields. The key step is based on the intramolecular hydroalkoxylation of unsaturated alcohols in a Lewis "superacid" catalysed process, which was found to be regiospecific and stereoselective. The $Al(OTf)_3$-catalysed cycloisomerisation afforded 1,3- and 1,4-disubstituted six-membered ring ethers with high selectivities in favour of the *cis* isomer.

Experimental Section

General: All reactions were performed under a nitrogen atmosphere by using standard Schlenk techniques. Solvents were dried according to standard procedures prior to use. Chemicals were obtained from commercial sources and were used without further purification. Gas chromatography analyses were performed with a Varian CP 3380 instrument equipped with a Chrompack fused silica capillary column (WCOT fused silica, 25 m × 0.5 mm i.d.). ^1H and ^{13}C

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NMR spectra were recorded with a Bruker AC-200 (200 MHz) spectrometer. Chemical shifts are reported in ppm relative to tetramethylsilane. GC–MS were realised with a Thermo Quest TRACE GC 2000 chromatograph (column DBTMS, 15 m × 0.20 mm i.d.) equipped with a mass selective detector Automass III multi.

General Procedure for Synthesis of Aldehydes 7a and 7b: To a stirred solution of butyl 2- or butyl 3-methyl-4-pentenoate (6.80 g, 40 mmol) and $RuCl_3{\cdot}xH_2O$ (1.4 mmol, 3.5 mol-%) in CH_3CN (240 mL) and distilled water (60 mL) was added $NaIO_4$ (17.11 g, 80 mmol) in portions over a period of 15 min at room temperature. The reaction was complete after 2 h, and the reaction mixture was quenched with saturated aqueous solution of $Na_2S_2O_3$. The layers were separated, and the aqueous layer was extracted three times with Et_2O. The combined organic layer was washed with water and brine, dried with $MgSO_4$, filtered and concentrated under reduced pressure. The crude product was analysed by ^1H NMR spectroscopy to determine the portion of α-diols formed. A glycol cleavage oxidation was then performed to transform the resulting diols (20%) into the corresponding aldehydes. To a vigorously stirred solution of silica gel supported $NaIO_4$ reagent (16.0 g) in CH_2Cl_2 (45 mL) was added the obtained crude product containing the vicinal diol (8 mmol) in CH_2Cl_2 (45 mL). The reaction was monitored by GC analysis and was complete after 30 min. The mixture was filtered, and the silica gel was thoroughly washed three times with CH_2Cl_2. The filtrate was concentrated to afford the aldehyde that was pure enough (>95%) to be used in the next step without further purification.

Butyl 3-Methyl-4-oxobutanoate (7a): ^1H NMR (200 MHz, $CDCl_3$): δ = 9.7 (d, J = 0.4 Hz, 1 H, H_{ald}), 4.1 (t, J = 6.7 Hz, 2 H, -OCH_2CH$_2$), 2.9–2.6 (m, 2 H, -CH_2CO), 2.5–2.3 (m, 1 H, -CHCH$_3$), 1.7–1.5 (m, 2 H, -CH$_2$CH_2CH$_2$-), 1.5–1.3 (m, 2 H, -CH$_2$CH_2CH$_3$), 1.2 (d, J = 7.3 Hz, 3 H, -CHCH_3), 0.9 (t, J = 7.3 Hz, 3 H, -CH$_2$CH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 203.2, 172.3, 65.0, 43.0, 35.4, 31.0, 19.5, 14.1, 13.8 ppm. MS (70 eV, EI): m/z (%) = 144 (9) $[M - 8]^{+\cdot}$, 116 (2), 99 (100), 88 (70), 73 (86), 71 (44), 57 (69).

Butyl 2-Methyl-4-oxobutanoate (7b): ^1H NMR (200 MHz, $CDCl_3$): δ = 9.8 (br. s, 1 H, H_{ald}), 4.1 (t, J = 6.6 Hz, 2 H, -OCH_2CH$_2$), 3.1–2.7 (m, 2 H, -CH_2CO), 2.6–2.4 (m, 1 H, -CHCH$_3$), 1.7–1.5 (m, 2 H, -CH$_2$CH_2CH$_2$-), 1.5–1.3 (m, 2 H, -CH$_2$CH_2CH$_3$), 1.2 (d, J = 7.1 Hz, 3 H, -CHCH_3), 0.9 (t, J = 7.2 Hz, 3 H, -CH$_2$CH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 200.6, 175.6, 65.1, 47.3, 34.1, 31.0, 19.5, 17.5, 14.1 ppm. MS (70 eV, EI): m/z (%) = 144 (4) $[M - 28]^{+\cdot}$, 116 (2), 99 (100), 88 (39), 73 (60), 71 (53), 57 (67).

General Procedure for Synthesis of Phosphonium Salt Derivatives 8: A suspension of triphenylphosphane (10.48 g, 40 mmol) and substituted allyl or benzyl halides (40 mmol) in toluene (70 mL) was stirred overnight at 110 °C. After the reaction was complete, the reaction mixture was cooled in an ice bath and the phosphonium salt was precipitated. The reaction crude was then filtered and washed with cold toluene. After drying it overnight under vacuum, the phosphonium salt was obtained as a white powder.

Prenyltriphenylphosphonium Bromide (8a): ^1H NMR (200 MHz, $CDCl_3$): δ = 7.9–7.6 (m, 15H_{Ar}), 5.2–5.0 [m, 1 H, -CH=C(CH$_3$)$_2$], 4.5 (dd, J = 14.6, 7.8 Hz, 2 H, -CH_2CH=), 1.7 (d, J = 5.7 Hz, 3 H, CH_3), 1.3 (d, J = 3.7 Hz, 3 H, CH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 143.8, 135.2 (3 C), 133.9 (6 C), 130.6 (6 C), 118.9 (3 C), 108.3, 26.1, 24.9, 18.6 ppm. ^{31}P NMR (200 MHz, $CDCl_3$): δ = 21.5 (s) ppm.

Benzyltriphenylphosphonium Chloride (8b): ^1H NMR (200 MHz, $CDCl_3$): δ = 7.8–7.5 (m, 15H_{Ar}), 7.2–6.9 (m, 5 H, -CH$_2$*Ph*), 5.5 (d, J = 14.5 Hz, 2 H, -CH_2Ph) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 135.3 (3 C), 134.9 (6 C), 133.1, 131.9 (2 C), 130.6 (6 C), 129.2 (2 C), 128.8, 119.2 (3 C), 31.5 ppm. ^{31}P NMR (200 MHz, $CDCl_3$): δ = 24.6 (s) ppm.

***ortho*-Methylbenzyltriphenylphosphonium Chloride (8c):** ^1H NMR (200 MHz, $CDCl_3$): δ = 7.9–7.6 (m, 15H_{Ar}), 7.3–6.9 (m, 4H_{Ar}), 5.2 (d, J = 14.0 Hz, 2 H, -CH_2-Ar), 1.7 (s, 3 H, CH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 139.0, 135.6 (3 C), 134.7 (6 C), 131.8, 131.4, 130.8 (6 C), 129.3, 127.2, 126.0, 118.9 (3 C), 29.3, 20.0 ppm. ^{31}P NMR: δ = 23.3 (s) ppm.

General Procedure for the Synthesis of Esters Derivatives 9: To a stirred suspension of NaH (0.432 g, 18 mmol) in THF (30 mL) was added phosphonium salt derivatives **8** (15 mmol) in portions over a period of 15 min at room temperature. Compounds **8a**–**c** were quantitatively prepared as white powders from a suspension of triphenylphosphane (10.48 g, 40 mmol) and substituted allyl halides (40 mmol) in toluene (70 mL) after stirring overnight at 110 °C. The colour turned from white to orange-red, indicating the formation of the corresponding ylide. After stirring for 1 h, aldehyde **7** (2.58 g, 15 mmol) was added in THF (5 mL) to the orange-red solution and stirring was continued at room temperature for 2 h. The reaction mixture was diluted with Et_2O and quenched with HCl (1 M). The layers were separated, and the aqueous layer was extracted three times with Et_2O. The combined organic layer was washed with water and brine, dried with $MgSO_4$, filtered and concentrated under reduced pressure. The residue was purified by column chromatography (pentane/Et_2O, 95:5) to afford esters **9a**–**e** as a colourless oils. The *Z*/*E* ratios were determined by GC analysis and ^1H NMR spectroscopy.

Butyl 3,7-Dimethylocta-4,6-dienoate [(*E*)-9a; *Z*/*E*, 28:72]: ^1H NMR (200 MHz, $CDCl_3$): δ = 6.2 [dd, J = 15.2, 10.7 Hz, 1 H, -CH=CH-CH=C(CH$_3$)$_2$], 5.8 [d, J = 10.7 Hz, 1 H, -CH=CH-CH=C(CH$_3$)$_2$], 5.4 [dd, J = 15.2, 7.6 Hz, 1 H, -CH=CH-CH=C(CH$_3$)$_2$], 4.1 (t, J = 6.6 Hz, 2 H, -OCH_2CH$_2$), 2.7–2.5 (m, 1 H, -CHCH$_3$), 2.3–2.1 (m, 2 H, -CH_2CO), 1.8 [s, 6 H, -CH=C(CH_3)$_2$], 1.7–1.5 (m, 2 H, -OCH$_2$CH_2), 1.5–1.3 (m, 2 H, -CH$_2$CH_2CH$_3$), 1.0 (d, J = 6.6 Hz, 3 H, -CHCH_3), 0.9 (t, J = 7.3 Hz, 3 H, -CH$_2$CH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 173.1, 135.6, 134.4, 126.0, 125.2, 64.5, 42.4, 34.4, 31.1, 26.3, 20.8, 19.6, 18.6, 14.1 ppm. MS (70 eV, EI): m/z (%) = 224 (62) $[M]^{+\cdot}$, 167 (38), 151 (16), 135 (7), 125 (20), 122 (73), 109 (100), 107 (95), 93 (71), 91 (62), 81 (64), 79 (63), 69 (49), 67 (73), 55 (59). Data for (*Z*)-**9a**: ^1H NMR (200 MHz, $CDCl_3$): δ = 6.1–6.0 [m, 2 H, -CH=CH-CH=C(CH$_3$)$_2$], 5.2–5.0 [m, 1 H, -CH=CH-CH=C(CH$_3$)$_2$], 4.1 (t, J = 6.7 Hz, 2 H, -OCH_2CH$_2$), 3.1–2.9 (m, 1 H, -CHCH$_3$), 2.3–2.1 (m, 2H$_2$, -CH_2CO), 1.8 [s, 6 H, -CH=C-(CH_3)$_2$], 1.7–1.5 (m, 2 H, -OCH$_2$CH_2), 1.5–1.3 (m, 2 H, -CH$_2$CH_2CH$_3$), 1.0 (d, J = 6.6 Hz, 3 H, -CHCH_3), 0.9 (t, J = 7.3 Hz, 3 H, -CH$_2$CH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 173.1, 136.3, 133.3, 124.6, 120.5, 64.5, 42.6, 31.1, 29.7, 26.7, 21.4, 19.6, 18.5, 14.1 ppm. MS (70 eV, EI): m/z (%) = 224 (38) $[M]^{+\cdot}$, 167 (20), 151 (8), 135 (4), 125 (9), 122 (68), 109 (100), 107 (95), 93 (65), 91 (42), 81 (53), 79 (52), 69 (28), 67 (65), 55 (41).

Butyl 3-Methyl-5-phenyl-4-pentenoate [(*E*)-9b; *Z*/*E*, 15:85]: ^1H NMR (200 MHz, $CDCl_3$): δ = 7.3–7.0 (m, 5H_{Ar}), 6.3 (d, J = 16.0 Hz, 1 H, -CH=CHPh), 6.1 (dd, J = 16.0, 7.4 Hz, 1 H, -CH=CHPh), 4.0 (t, J = 6.4 Hz, 2 H, -OCH_2CH$_2$), 2.9–2.7 (m, 1 H, -CHCH$_3$), 2.4–2.2 (m, 2 H, -CH_2CO), 1.6–1.4 (m, 2 H, -CH$_2$CH_2CH$_2$), 1.4–1.1 (m, 2 H, -CH$_2$CH_2CH$_3$), 1.1 (d, J = 6.7 Hz, 3 H, -CHCH_3), 0.8 (t, J = 7.2 Hz, 3 H, -CH$_2$CH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 172.9, 137.8, 134.6, 129.3, 129.2 (2 C), 127.5, 126.5 (2 C), 64.6, 42.2, 34.5, 31.1, 20.7, 19.5, 14.1 ppm. MS (70 eV, EI): m/z (%) = 246 (7) $[M]^{+\cdot}$, 190 (2), 171 (3), 144 (48), 131 (100),

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129 (97), 115 (24), 103 (8), 91 (59), 77 (15), 65 (8), 57 (8), 51 (9). Data for (*Z*)-**9b**: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.3–7.0 (m, $5H_{Ar}$), 6.4 (d, *J* = 11.6 Hz, 1 H, -CH=C*H*Ph), 5.4 (dd, *J* = 11.6, 10.4 Hz, 1 H, -C*H*=CHPh), 4.0 (t, *J* = 6.4 Hz, 2 H, -OCH_2CH$_2$), 3.3–3.1 (m, 1 H, -C*H*CH$_3$), 2.4–2.2 (m, 2 H, -CH_2CO), 1.6–1.4 (m, 2 H, -CH$_2$CH_2CH$_2$), 1.4–1.1 (m, 2 H, -CH$_2$CH_2CH$_3$), 1.0 (d, *J* = 6.7 Hz, 3 H, -CHCH_3), 0.8 (t, *J* = 7.2 Hz, 3 H, -CH$_2$CH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 172.9, 136.9, 134.4, 129.0, 129.2 (2 C), 127.1, 126.5 (2 C), 66.3, 42.6, 31.0, 30.1, 21.3, 19.5, 15.7 ppm. MS (70 eV, EI): *m*/*z* (%) = 246 (7) $[M]^{+\cdot}$, 190 (2), 171 (3), 144 (48), 131 (100), 129 (97), 115 (24), 103 (8), 91 (59), 77 (15), 65 (8), 57 (8), 51 (9).

Butyl 3-Methyl-5-*ortho*-tolyl-4-pentenoate [(*E*)-9c; *Z*/*E*, 14:86]: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.3–7.0 (m, $4H_{Ar}$), 6.6 (d, *J* = 15.7 Hz, 1 H, -CH=C*H*Ph), 6.0 (dd, *J* = 15.7, 7.6 Hz, 1 H, -C*H*=CHPh), 4.1 (t, *J* = 6.7 Hz, 2 H, -OCH_2CH$_2$), 2.9–2.7 (m, 1 H, -C*H*CH$_3$), 2.4 (dd, *J* = 7.2, 4.2 Hz, 2 H, -CH_2CO), 2.3 [s, 3 H, CH$_3$(tolyl)], 1.7–1.5 (m, 2 H, -CH$_2$CH_2CH$_2$), 1.5–1.2 (m, 2 H, -CH$_2$CH_2CH$_3$), 1.2 (d, *J* = 6.8 Hz, 3 H, -CHCH_3), 0.9 (t, *J* = 7.2 Hz, 3 H, -CH$_2$CH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 172.9, 137.0, 136.1, 135.5, 130.6, 127.5, 127.4, 126.2, 125.9, 64.7, 42.4, 34.9, 31.1, 20.8, 20.2, 19.6, 14.1 ppm. MS (70 eV, EI): *m*/*z* (%) = 260 (15) $[M]^{+\cdot}$, 204 (3), 187 (4), 158 (38), 145 (93), 143 (100), 129 (32), 115 (27), 105 (47), 91 (22), 77 (12), 65 (8), 57 (10). Data for (*Z*)-**9c**: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.3–7.0 (m, $4H_{Ar}$), 6.4 (d, *J* = 11.4 Hz, 1 H, -CH=C*H*Ph), 5.5 (dd, *J* = 11.4, 10.3 Hz, 1 H, -C*H*=CHPh), 4.1 (t, *J* = 6.7 Hz, 2 H, -OCH_2CH$_2$), 2.9–2.7 (m, 1 H, -C*H*CH$_3$), 2.4 (dd, *J* = 7.2, 4.2 Hz, 2 H, -CH_2CO), 2.3 [s, 3 H, CH$_3$(tolyl)], 1.7–1.5 (m, 2H_2, -CH$_2$CH_2CH$_2$), 1.5–1.2 (m, 2 H, -CH$_2$CH_2CH$_3$), 1.1 (d, *J* = 6.8 Hz, 3 H, -CHCH_3), 0.9 (t, *J* = 7.2 Hz, 3 H, -CH$_2$CH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 172.7, 136.7, 136.1, 135.5, 130.6, 130.1, 130.0, 129.1, 128.2, 64.6, 42.5, 34.9, 31.0, 20.8, 21.4, 19.5, 14.1 ppm. MS (70 eV, EI): *m*/*z* (%) = 260 (12) $[M]^{+\cdot}$, 204 (2), 187 (4), 158 (38), 145 (90), 143 (100), 129 (32), 115 (28), 105 (47), 91 (24), 77 (15), 65 (8), 57 (13).

Butyl 2,7-Dimethylocta-4,6-dienoate [(*E*)-9d; *Z*/*E*, 45:55]: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 6.2 [dd, *J* = 14.9, 10.9 Hz, 1 H, -CH=C*H*-CH=C(CH$_3$)$_2$], 5.7 [d, *J* = 10.9 Hz, 1 H, -CH=CH-C*H*=C(CH$_3$)$_2$], 5.4 [dt, *J* = 14.9, 7.2 Hz, 1 H, -C*H*=CH-CH=C(CH$_3$)$_2$], 4.0 (t, *J* = 6.6 Hz, 2 H, -OCH_2CH$_2$), 2.6–2.1 [m, 3 H, -C*H*(CH$_3$)CH_2-], 1.7 [s, 6 H, -CH=C(CH_3)$_2$], 1.6–1.4 (m, 2 H, -OCH$_2$CH_2), 1.4–1.2 (m, 2 H, -CH$_2$CH_2CH$_3$), 1.1 (d, *J* = 6.8 Hz, 3 H, -CHCH_3), 0.9 (t, *J* = 7.3 Hz, 3 H, -CH$_2$CH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 176.6, 134.1, 129.3, 128.3, 125.2, 64.5, 40.3, 37.4, 31.1, 26.3, 19.6, 18.6, 17.0, 14.1 ppm. MS (70 eV, EI): *m*/*z* (%) = 224 (32) $[M]^{+\cdot}$, 168 (2), 151 (7), 122 (39), 109 (100), 107 (22), 95 (100), 81 (16), 79 (20), 69 (6), 67 (30), 55 (28). Data for (*Z*)-**9d**: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 6.3–6.1 [m, 1 H, -CH=C*H*-CH=C(CH$_3$)$_2$], 6.0 [d, *J* = 11.4 Hz, 1 H, -CH=CH-C*H*=C(CH$_3$)$_2$], 5.2 [dt, *J* = 10.6, 7.2 Hz, 1 H, -C*H*=CH-CH=C(CH$_3$)$_2$], 4.0 (t, *J* = 6.6 Hz, 2 H, -OCH_2CH$_2$), 2.6–2.1 [m, 3 H, -C*H*(CH$_3$)CH_2-], 1.7 [s, 6 H, -CH=C(CH_3)$_2$], 1.6–1.4 (m, 2 H, -OCH$_2$CH_2), 1.4–1.2 (m, 2 H, -CH$_2$CH_2CH$_3$), 1.1 (d, *J* = 6.7 Hz, 3 H, -CHCH_3), 0.9 (t, *J* = 7.3 Hz, 3 H, -CH$_2$CH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 176.7, 136.3, 127.0, 125.8, 120.5, 64.6, 40.2, 31.9, 31.1, 26.3, 19.6, 18.5, 17.0, 14.1 ppm. MS (70 eV, EI): *m*/*z* (%) = 224 (32) $[M]^{+\cdot}$, 168 (2), 151 (7), 122 (39), 109 (100), 107 (22), 95 (100), 81 (16), 79 (20), 69 (6), 67 (30), 55 (28).

Butyl 2-Methyl-5-phenyl-4-pentenoate [(*E*)-9e; *Z*/*E*, 30:70]: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.4–7.1 (m, $5H_{Ar}$), 6.4 (d, *J* = 15.8 Hz, 1 H, -CH=C*H*Ph), 6.1 (dt, *J* = 15.8, 7.1 Hz, 1 H, -C*H*=CHPh), 4.0 (t, *J* = 6.6 Hz, 2 H, -OCH_2CH$_2$), 2.7–2.5 (m, 2 H, -CHCH$_3$CH_2), 2.5–2.3 (m, 1 H, -C*H*CH$_3$CH$_2$), 1.7–1.5 (m, 2 H, -OCH$_2$CH_2), 1.5–1.3 (m, 2 H, -CH$_2$CH_2CH$_3$), 1.2 (d, *J* = 6.7 Hz, 3 H, -CHCH_3), 0.9 (t, *J* = 7.2 Hz, 3 H, -CH$_2$CH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 176.5, 137.8, 132.4, 129.2, 128.9 (2 C), 127.5, 126.5 (2 C), 64.6, 40.2, 37.5, 31.2, 19.6, 17.2, 14.1 ppm. MS (70 eV, EI): *m*/*z* (%) = 246 (22) $[M]^{+\cdot}$, 190 (6), 173 (13), 144 (70), 129 (24), 115 (42), 103 (6), 91 (46), 77 (14), 65 (11), 57 (18), 51 (10). Data for (*Z*)-**9e**: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.4–7.1 (m, $5H_{Ar}$), 6.5 (d, *J* = 11.6 Hz, 1 H, -CH=C*H*Ph), 5.6 (dt, *J* = 11.6, 7.2 Hz, 1 H, -C*H*=CHPh), 4.0 (t, *J* = 6.6 Hz, 2 H, -OCH_2CH$_2$), 2.7–2.5 (m, 2 H, -CHCH$_3$CH_2), 2.5–2.3 (m, 1 H, -C*H*CH$_3$CH$_2$), 1.7–1.5 (m, 2 H, -OCH$_2$CH_2), 1.5–1.3 (m, 2 H, -CH$_2$CH_2CH$_3$), 1.2 (d, *J* = 6.7 Hz, 3 H, -CHCH_3), 0.9 (t, *J* = 7.2 Hz, 3 H, -CH$_2$CH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 176.5, 137.78, 131.0, 129.7, 128.6 (2 C), 127.7 (2 C), 126.1, 64.6, 40.4, 32.8, 31.1, 19.6, 17.2, 14.1 ppm. MS (70 eV, EI): *m*/*z* (%) = 246 (8) $[M]^{+\cdot}$, 190 (3), 173 (8), 144 (38), 129 (14), 115 (21), 103 (3), 91 (24), 77 (9), 65 (7), 57 (11), 51 (6).

General Procedure for Synthesis of Unsaturated Alcohols 6: To a stirred suspension of $LiAlH_4$ (0.378 g, 10 mmol) in THF (20 mL) was added ester **9** (10 mmol) in THF (5 mL) at room temperature. After being stirred for 1 h, the reaction mixture was cooled with an ice bath and carefully quenched with water. The mixture was then diluted with Et_2O and with HCl (0.1 M). The layers were separated, and the aqueous layer was extracted three times with Et_2O. The combined organic layer was washed with water and brine and dried with $MgSO_4$. After filtration and removal of the solvent under reduced pressure, alcohol **6** was obtained as a colourless oil. The *Z*/*E* ratios were determined by GC analysis and were similar to the ^{1}H NMR integration of characteristic ethylenic protons.

3,7-Dimethylocta-4,6-dienol [(*E*)-6a; *Z*/*E*, 28:72]:[21] ^{1}H NMR (200 MHz, $CDCl_3$): δ = 6.5 [dd, *J* = 15.0, 10.9 Hz, 1 H, -CH=C*H*-CH=C(CH$_3$)$_2$], 5.8 [d, *J* = 10.9 Hz, 1 H, -CH=CH-C*H*=C(CH$_3$)$_2$], 5.4 [dd, *J* = 15.0, 8.2 Hz, 1 H, -C*H*=CH-CH=C(CH$_3$)$_2$], 3.6 (t, *J* = 6.6 Hz, 2 H, -CH_2OH), 2.4 (m, 1 H, -C*H*CH$_3$), 1.7 [s, 6 H, -CH=C(CH_3)$_2$], 1.6–1.3 (m, 2 H, -CH_2CH$_2$OH), 1.0 (d, *J* = 6.7 Hz, 3 H, -CHCH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 137.4, 133.9, 125.9, 125.3, 61.7, 40.3, 34.5, 26.3, 21.5, 18.6 ppm. MS (70 eV, EI): *m*/*z* (%) = 154 (24) $[M]^{+\cdot}$, 139 (13), 121 (48), 109 (80), 95 (51), 93 (59), 91 (44), 81 (73), 79 (58), 77 (40), 69 (57), 67 (100), 55 (62). Data for (*Z*)-**6a**: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 6.2–6.0 [m, 2 H, -CH=C*H*-C*H*=C(CH$_3$)$_2$], 5.1 [dd, *J* = 9.7, 9.7 Hz, 1 H, -C*H*=CH-CH=C(CH$_3$)$_2$], 3.6 (t, *J* = 6.6 Hz, 2 H, -CH_2OH), 2.8–2.6 (m, 1 H, -C*H*CH$_3$), 1.7 [s, 6 H, -CH=C(CH_3)$_2$], 1.6–1.3 (m, 2 H, -CH_2CH$_2$OH), 1.0 (d, *J* = 6.7 Hz, 3 H, -CHCH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 136.3, 135.3, 124.4, 120.5, 61.8, 40.6, 29.3, 26.7, 21.8, 18.5 ppm. MS (70 eV, EI): *m*/*z* (%) = 154 (24) $[M]^{+\cdot}$, 139 (13), 121 (48), 109 (80), 95 (51), 93 (59), 91 (44), 81 (73), 79 (58), 77 (40), 69 (54), 67 (100), 55 (60).

3-Methyl-5-phenyl-4-pentenol [(*E*)-6b; *Z*/*E*, 15:85]:[22] ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.3–7.0 (m, $5H_{Ar}$), 6.3 (d, *J* = 15.9 Hz, 1 H, -CH=C*H*Ph), 6.0 (dd, *J* = 15.9, 8.1 Hz, 1 H, -C*H*=CHPh), 3.6 (t, *J* = 6.6 Hz, 2 H, -CH_2OH), 2.5–2.3 (m, 1 H, -C*H*CH$_3$), 1.7 (br. s, 1 H, -CH$_2$O*H*), 1.6–1.4 (m, 2 H, -CH_2CH$_2$OH), 1.0 (d, *J* = 6.7 Hz, 3 H, -CHCH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 138.0, 136.4, 129.0, 128.9 (2 C), 127.4, 126.4 (2 C), 61.6, 40.1, 34.6, 21.3 ppm. MS (70 eV, EI): *m*/*z* (%) = 176 (15) $[M]^{+\cdot}$, 157 (5), 143 (68), 131 (86), 128 (50), 116 (28), 115 (45), 103 (15), 91 (100), 77 (26), 71 (13), 65 (13), 63 (8), 51 (14). Data for (*Z*)-**6b**: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.3–7.0 (m, $5H_{Ar}$), 6.35 (d, *J* = 11.6 Hz, 1 H, -CH=C*H*Ph), 5.4 (dd, *J* = 11.6, 10.5 Hz, 1 H, -C*H*=CHPh), 3.6 (t, *J* = 6.6 Hz, 2 H, -CH_2OH), 3.0–2.7 (m, 1 H, -C*H*CH$_3$), 1.7 (br. s, 1 H, -CH$_2$O*H*), 1.6–1.4 (m, 2 H, -CH_2CH$_2$OH), 0.95 (d, *J* =

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6.7 Hz, 3 H, -CHCH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 138.9, 134.5, 129.1, 128.9 (2 C), 127.1, 126.4 (2 C), 61.6, 40.7, 29.5, 21.6 ppm. MS (70 eV, EI): *m*/*z* (%) = 176 (15) $[M]^{+\cdot}$, 157 (5), 143 (68), 131 (86), 128 (50), 116 (28), 115 (45), 103 (15), 91 (100), 77 (26), 71 (13), 65 (13), 63 (8), 51 (14).

3-Methyl-5-*ortho*-tolyl-4-pentenol [(*E*)-6c; *Z*/*E*, 14:86]: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.2–7.0 (m, 4H_{Ar}), 6.6 (d, *J* = 15.8 Hz, 1 H, -CH=C*H*Ph), 6.0 (dd, *J* = 15.8, 8.3 Hz, 1 H, -C*H*=CHPh), 3.7 (t, *J* = 6.6 Hz, 2 H, -CH_2OH), 2.7–2.4 (m, 1 H, -C*H*CH_3), 2.3 [s, 3 H, CH_3(tolyl)], 1.7–1.5 (m, 2 H, -C$H_2$$CH_2$OH), 1.5 (br. s, 1 H, -$CH_2$O*H*), 1.1 (d, *J* = 6.8 Hz, 3 H, -CHCH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 137.9, 137.1, 135.4, 130.6, 127.4, 126.9, 126.4, 125.9, 61.7, 40.2, 35.0, 21.4, 20.3 ppm. MS (70 eV, EI): *m*/*z* (%) = 190 (25) $[M]^{+\cdot}$, 172 (10), 157 (68), 145 (90), 129 (48), 115 (48), 105 (100), 91 (62), 77 (32), 65 (18), 51 (13). Data for (*Z*)-**6c**: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.4–7.3 (m, 4H_{Ar}), 6.4 (d, *J* = 11.4 Hz, 1 H, -CH=C*H*Ph), 5.5 (dd, *J* = 11.4, 10.5 Hz, 1 H, -C*H*=CHPh), 3.7 (t, *J* = 6.6 Hz, 2 H, -CH_2OH), 2.7–2.4 (m, 1 H, -C*H*CH_3), 2.2 [s, 3 H, CH_3(tolyl)], 1.7–1.5 (m, 2 H, -C$H_2$$CH_2$OH), 1.5 (br. s, 1 H, -$CH_2$O*H*), 1.0 (d, *J* = 6.7 Hz, 3 H, -CHCH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 138.5, 135.4, 130.6, 130.2, 129.2, 128.1, 127.4, 126.4, 63.2, 40.5, 35.3, 21.7, 19.3 ppm. MS (70 eV, EI): *m*/*z* (%) = 190 (16) $[M]^{+\cdot}$, 172 (8), 157 (68), 145 (84), 129 (48), 115 (53), 105 (100), 91 (64), 77 (35), 65 (18), 51 (13).

2,7-Dimethylocta-4,6-dienol [(*E*)-6d; *Z*/*E*, 45:55]:[23] ^{1}H NMR (200 MHz, $CDCl_3$): δ = 6.2 [dd, *J* = 14.9, 10.9 Hz, 1 H, -CH=C*H*-CH=C$(CH_3)_2$], 5.7 [d, *J* = 10.9 Hz, 1 H, -CH=CH-C*H*=C$(CH_3)_2$], 5.5 [dt, *J* = 14.9, 7.2 Hz, 1 H, -C*H*=CH-CH=C$(CH_3)_2$], 3.6–3.3 (m, 2 H, -CH_2OH), 2.3–1.7 [m, 3 H, -CH_2C*H*(CH_3)OH], 1.7 [s, 6 H, -CH=C(CH_3)$_2$], 1.4 [br. s, 1 H, -CH(CH_3)O*H*], 0.9 (d, *J* = 6.7 Hz, 3 H, -CHCH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 133.7, 129.8, 128.8, 125.3, 68.4, 37.2, 36.6, 26.3, 16.9 (2 C) ppm. MS (70 eV, EI): *m*/*z* (%) = 154 (27) $[M]^{+\cdot}$, 139 (2), 121 (12), 107 (8), 95 (100), 93 (32), 81 (34), 79 (28), 77 (19), 69 (15), 67 (62), 55 (42). Data for (*Z*)-**6d**: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 6.3–6.1 [m, 1 H, -CH=C*H*-CH=C$(CH_3)_2$], 6.0 [d, *J* = 11.5 Hz, 1 H, -CH=CH-C*H*=C$(CH_3)_2$], 5.3 [m, 1 H, -C*H*=CH-CH=C$(CH_3)_2$], 3.6–3.3 (m, 2 H, -CH_2OH), 2.3–1.7 [m, 3 H, -CH_2C*H*(CH_3)OH], 1.7 [s, 6 H, -CH=C(CH_3)$_2$], 1.4 [br. s, 1 H, -CH(CH_3)O*H*], 0.9 (d, *J* = 6.7 Hz, 3 H, -CHCH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 133.0, 127.5, 126.4, 120.6, 68.4, 36.8, 31.6, 26.7, 17.0 (2 C) ppm. MS (70 eV, EI): *m*/*z* (%) = 154 (25) $[M]^{+\cdot}$, 139 (2), 121 (14), 107 (9), 95 (100), 93 (35), 81 (41), 79 (32), 77 (22), 69 (19), 67 (72), 55 (48).

2-Methyl-5-phenyl-4-pentenol [(*E*)-6e; *Z*/*E*, 30:70]:[24] ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.4–7.1 (m, 5H_{Ar}), 6.4 (d, *J* = 15.8 Hz, 1 H, -CH=C*H*Ph), 6.1 (dt, *J* = 15.8, 7.1 Hz, 1 H, -C*H*=CHPh), 3.6–3.4 (m, 2 H, -CH_2OH), 2.5–2.2 (m, 1 H, -C*H*HCH=), 2.2–2.0 (m, 1 H, -CH*H*CH=), 1.9–1.7 (m, 1 H, -C*H*CH_3), 1.6 [br. s, 1 H, -CH(CH_3)O*H*], 1.0 (d, *J* = 6.7 Hz, 3 H, -CHCH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 137.8, 131.6, 128.9, 128.6 (2 C), 127.1, 126.1 (2 C), 68.0, 37.0, 36.2, 16.2 ppm. MS (70 eV, EI): *m*/*z* (%) = 176 (39) $[M]^{+\cdot}$, 143 (33), 129 (79), 117 (100), 91 (99.7), 77 (54), 65 (56), 55 (10). Data for (*Z*)-**6e**: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.4–7.1 (m, 5H_{Ar}), 6.5 (d, *J* = 11.6 Hz, 1 H, -CH=C*H*Ph), 5.6 (dt, *J* = 11.6, 7.2 Hz, 1 H, -C*H*=CHPh), 3.6–3.4 (m, 2 H, -CH_2OH), 2.5–2.2 (m, 1 H, -C*H*HCH=), 2.2–2.0 (m, 1 H, -CH*H*CH=), 1.9–1.7 (m, 1 H, -C*H*CH_3), 1.6 [br. s, 1 H, -CH(CH_3)O*H*], 0.9 (d, *J* = 6.6 Hz, 3 H, -CHCH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 137.7, 131.0, 130.2, 128.3 (2 C), 126.7, 126.1 (2 C), 68.0, 36.7, 32.2, 16.2 ppm. MS (70 eV, EI): *m*/*z* (%) = 176 (25) $[M]^{+\cdot}$, 143 (31), 129 (53), 115 (99.9), 104 (44), 91 (100), 77 (61), 65 (59), 55 (12).

General Procedure for the Al(OTf)$_3$-Catalysed Cycloisomerisation of Unsaturated Alcohols 6: A mixture of unsaturated alcohol (3 mmol) and Al(OTf)$_3$ (71 mg, 0.15 mmol) in distilled CH_2Cl_2 or $ClCH_2CH_2Cl$ (15 mL) was stirred at reflux for 1 to 3 h. The progress of the reaction was monitored by GC analysis. After completion of the reaction, the mixture was cooled and quenched with HCl (1 M). The layers were separated, and the aqueous layer was extracted three times with Et_2O. The combined organic layer was washed with water and brine and dried with $MgSO_4$. After filtration and removal of the solvent under reduced pressure, the residue was purified by column chromatography (pentane/Et_2O, 95:5) to afford cyclic ethers **1**–**5**.

Rose Oxide (*cis*-1; *cis*/*trans*, 94:6): ^{1}H NMR (200 MHz, $CDCl_3$): δ = 5.2 [dsept., *J* = 8.1, 1.3 Hz, 1 H, -C*H*=C$(CH_3)_2$], 4.0–3.9 (m, 2 H, -C*H*-O-CH*H*-), 3.5 (ddd, *J* = 12.4, 12.1, 2.3 Hz, 1 H, -CH-O-C*H*H-), 1.73 [d, *J* = 1.3 Hz, 3 H, -CH=C(CH_3)$_2$], 1.68 [d, *J* = 1.3 Hz, 3 H, -CH=C(CH_3)$_2$], 1.7–1.5 [m, 3 H, -C*H*(CH_3)-CH_2-CH-O], 1.3–1.0 (m, 2 H, -CH_2-CH_2-O), 0.9 (d, *J* = 6.3 Hz, 3 H, -CHCH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 135.5, 126.8, 75.0, 68.3, 41.2, 34.8, 30.7, 26.1, 22.7, 18.8 ppm. MS (70 eV, EI): *m*/*z* (%) = 154 (63) $[M]^{+\cdot}$, 139 (93), 121 (16), 112 (34), 109 (26), 97 (53), 95 (32), 93 (44), 91 (34), 83 (89), 69 (100), 55 (89). Data for *trans*-**1**: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 5.3 [m, 1 H, -C*H*=C$(CH_3)_2$], 4.4–4.3 (m, 1 H, -C*H*-O-CH_2-), 3.8–3.7 (m, 2 H, -CH-O-CH_2-), 1.73 [d, *J* = 1.3 Hz, 3 H, -CH=C(CH_3)$_2$], 1.68 [d, *J* = 1.3 Hz, 3 H, -CH=C(CH_3)$_2$], 1.7–1.5 [m, 3 H, -C*H*(CH_3)-CH_2-CH-O], 1.3–1.0 (m, 2 H, -CH_2-CH_2-O), 0.9 (d, *J* = 6.3 Hz, 3 H, -CHCH_3) ppm. MS (70 eV, EI): *m*/*z* (%) = 154 (12) $[M]^{+\cdot}$, 139 (83), 121 (4), 112 (4), 109 (5), 97 (6), 95 (4), 93 (7), 91 (4), 83 (55), 69 (100), 55 (50).

Doremox® (*cis*-2; *cis*/*trans*, 95:5): ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.3–7.1 (m, 5H_{Ar}), 4.2 (dd, *J* = 11.5, 1.9 Hz, 1 H, -C*H*-O), 4.1 (ddd, *J* = 11.5, 4.6, 1.5 Hz, 1 H, -CH*H*-O), 3.5 (ddd, *J* = 12.3, 12.2, 2.3 Hz, 1 H, -C*H*H-O), 1.8–1.5 [m, 3 H, -C*H*(CH_3)-CH_2-CH-O], 1.4–1.1 (m, 2 H, -CH_2-CH_2-O), 0.9 (d, *J* = 6.7 Hz, 3 H, -CHCH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 143.6, 128.7 (2 C), 127.7, 126.3 (2 C), 80.3, 69.0, 43.1, 34.9, 31.2, 22.7 ppm. MS (70 eV, EI): *m*/*z* (%) = 176 (48) $[M]^{+\cdot}$, 175 (45), 143 (2), 128 (4), 115 (6), 105 (100), 99 (4), 91 (32), 77 (48), 70 (17), 69 (26), 65 (6), 55 (42). Data for *trans*-**2**: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.3–7.1 (m, 5H_{Ar}), 4.6 (dd, *J* = 9.7, 3.2 Hz, 1 H, -C*H*-O), 3.8–3.7 (m, 2 H, -CH_2-O), 1.8–1.5 [m, 3 H, -C*H*(CH_3)-CH_2-CH-O], 1.4–1.1 (m, 2 H, -CH_2-CH_2-O), 1.1 (d, *J* = 7.0 Hz, 3 H, -CHCH_3) ppm. MS (70 eV, EI): *m*/*z* (%) = 176 (48) $[M]^{+\cdot}$, 175 (45), 143 (2), 128 (4), 115 (6), 105 (100), 99 (4), 91 (32), 77 (48), 70 (17), 69 (26), 65 (6), 55 (42).

4-Methyl-2-*ortho*-tolyltetrahydropyran (*cis*-3; *cis*/*trans*, 94:6): ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.4–7.0 (m, 4H_{Ar}), 4.4 (dd, *J* = 11.3, 1.5 Hz, 1 H, -C*H*-O), 4.1 (ddd, *J* = 11.9, 4.6, 1.2 Hz, 1 H, -CH*H*-O), 3.6 (ddd, *J* = 11.9, 11.8, 2.1 Hz, 1 H, -C*H*H-O), 2.3 [s, 3 H, CH_3(tolyl)], 1.8–1.4 [m, 3 H, -C*H*(CH_3)-CH_2-CH-O], 1.4–1.1 (m, 2 H, -CH_2-CH_2-O), 0.9 (d, *J* = 6.2 Hz, 3 H, -CHCH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 141.6, 134.8, 130.6, 127.5, 126.6, 125.8, 77.1, 69.1, 41.7, 35.0, 31.3, 22.7, 19.4 ppm. MS (70 eV, EI): *m*/*z* (%) = 190 (36) $[M]^{+\cdot}$, 175 (26), 172 (14), 157 (25), 145 (14), 129 (6), 119 (100), 105 (80), 91 (94), 77 (22), 69 (20), 65 (19), 51 (38). $C_{13}H_{18}O$ (190.28): calcd. C 82.06, H 9.53; found C 82.35, H 9.58. Data for *trans*-**3**: MS (70 eV, EI): *m*/*z* (%) = 190 (36) $[M]^{+\cdot}$, 175 (26), 172 (14), 157 (25), 145 (14), 129 (6), 119 (100), 105 (80), 91 (94), 77 (22), 69 (20), 65 (19), 51 (38).

2-Isobutenyl-5-methyltetrahydropyran (*cis*-4; *cis*/*trans*, 90:10): ^{1}H NMR (200 MHz, $CDCl_3$): δ = 5.1 [dsept., *J* = 8.1, 1.3 Hz, 1 H, -C*H*=C$(CH_3)_2$], 3.9–3.7 (m, 2 H, -C*H*-O-CH*H*-), 3.0 (dd, *J* = 11.1, 11.0 Hz, 1 H, -CH-O-C*H*H-), 1.8–1.7 (m, 1 H, -C*H*CH_3), 1.63 [d,

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J = 1.3 Hz, 3 H, -CH=C(CH_3)$_2$], 1.60 [d, J = 1.3 Hz, 3 H, -CH=C(CH_3)$_2$], 1.5–1.2 (m, 3 H, -CH_2-CHHCH-O), 1.2–1.0 (m, 1 H, -CH$_2$CHHCH-O), 0.7 (d, J = 6.6 Hz, 3 H, -CHCH_3) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 135.7, 126.6, 75.0, 74.9, 32.8, 32.5, 31.0, 26.1, 18.8, 17.7 ppm. MS (70 eV, EI): *m*/*z* (%) = 154 (16) $[M]^{+\cdot}$, 139 (63), 112 (6), 87 (47), 85 (47), 69 (100), 55 (45). Data for *trans*-**4**: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 5.2 [dsept., J = 8.0, 1.4 Hz, 1 H, -CH=C(CH$_3$)$_2$], 4.0–3.9 (m, 1 H, -CH-O-CH$_2$-), 3.6–3.5 (m, 2 H, -CH-O-CH_2-), 1.8–1.7 (m, 1 H, -CHCH$_3$), 1.63 [d, J = 1.3 Hz, 3 H, -CH=C(CH_3)$_2$], 1.60 [d, J = 1.3 Hz, 3 H, -CH=C(CH_3)$_2$], 1.5–1.2 (m, 3 H, -CH_2-CHHCH-O), 1.2–1.0 (m, 1 H, -CH$_2$CHHCH-O), 1.0 (d, J = 7.2 Hz, 3 H, -CHCH_3) ppm. MS (70 eV, EI): *m*/*z* (%) = 154 (5) $[M]^{+\cdot}$, 139 (53), 112 (3), 85 (42), 69 (100), 55 (63).

5-Methyl-2-phenyltetrahydropyran (*cis*-5; *cis*/*trans*, 86:14): ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.4–7.1 (m, 5H$_{Ar}$), 4.2 (dd, J = 11.0, 2.2 Hz, 1 H, -CH-O-CH$_2$-), 4.0 (ddd, J = 11.1, 4.3, 2.2 Hz, 1 H, -CH-O-CHH-), 3.2 (dd, J = 11.1, 11.0 Hz, 1 H, -CH-O-CHH-), 2.0–1.3 [m, 5 H, -CH_2CH_2CH(CH$_3$)-], 0.9 [d, J = 6.6 Hz, 3 H, -CH(CH_3)] ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 143.5, 128.7 (2 C), 127.7, 126.3 (2 C), 80.2, 75.6, 34.4, 32.3, 31.1, 17.7 ppm. MS (70 eV, EI): *m*/*z* (%) = 176 (94) $[M]^{+\cdot}$, 129 (3), 117 (9), 105 (100), 91 (50), 77 (88), 55 (76). Data for *trans*-**5**: ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.4–7.1 (m, 5H$_{Ar}$), 4.4–4.3 (m, 1 H, -CH-O-CH$_2$-), 3.8–3.7 (m, 2 H, -CH-O-CH_2-), 2.0–1.5 [m, 5 H, -CH_2CH_2CH(CH$_3$)-], 1.1 [d, J = 6.9 Hz, 3 H, -CH(CH_3)] ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 143.5, 128.7 (2 C), 127.7, 126.3 (2 C), 80.2, 73.5, 29.9, 29.1, 28.5, 17.1 ppm. MS (70 eV, EI): *m*/*z* (%) = 176 (94) $[M]^{+\cdot}$, 129 (3), 117 (9), 105 (100), 91 (50), 77 (88), 55 (76).

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