Alkyl-Group Selection in an Acidic-Surfactant-Promoted Reaction of Homoallyl Alcohols and Aldehydes in Water

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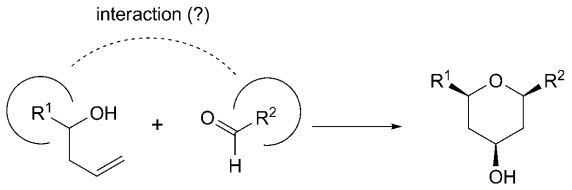
The hydrophobic effect in the reaction of a homoallyl alcohol with an aldehyde (*Yadav*'s reaction system) under aqueous conditions in the presence of an acidic surfactant was studied indicating the presence of the alkyl-substituent effect, although not a dramatic one. The DBSA-promoted reaction proceeds relatively faster when both the homoallyl alcohol and the aldehyde carry a cycloalkyl group (DBSA = 4-dodecylbenzenesulfonic acid). In contrast, the reaction of the substrates having an unbranched alkyl group is relatively more favorable in SDS/HCl than in DBSA (SDS = sodium dodecyl sulfate).

Introduction. – Organic reactions in H_2O have been extensively developed recently [1]. In the reactions of organic substrates in H_2O, hydrophobic interaction is an important factor [2], by which various organic reactions are thought to be controlled. Thus, it is essential to know the extent of the hydrophobic interaction in an aqueous organic reaction. For this purpose, as a model study, we planned to evaluate the hydrophobic effect in *Yadav*'s reaction system [3–6], namely in the reaction of a homoallyl alcohol with an aldehyde to afford a tetrahydro-2*H*-pyran-4-ol compound (*Scheme 1*) *via* a *Prins*-type cyclization [7]. In the reaction, the hydrophobic interaction between R^1 and R^2 is expected to be present in the initial hemiacetal formation. The reaction is known to proceed smoothly in dichloromethane [3], in 1,2-dichloroethane [4], or in an ionic organic solvent [5] giving the tetrahydro-2*H*-pyran-4-ol derivatives. A phosphomolybdic acid promoted reaction in H_2O has been reported recently [6].

Scheme 1

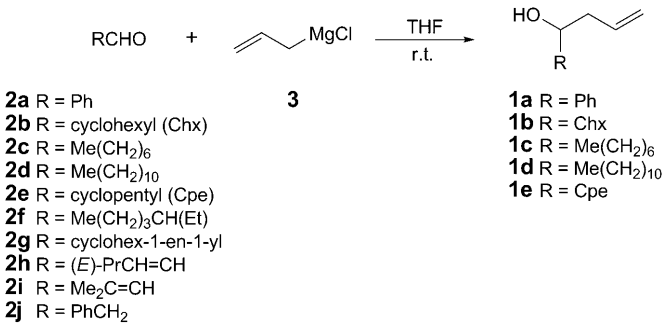


In the aqueous organic reactions, surfactants are often used to provide the reaction media by dissolving H_2O-insoluble organic materials. Among the various surfactants, DBSA (4-dodecylbenzenesulfonic acid) is not only a surfactant but also an acid. Therefore, the compound is useful in the acid-promoted reactions in H_2O, such as

esterification [8], substitution [9], and cyclization [10] reactions. Since *Yadav*'s reaction is also promoted under acidic conditions, we planned to use DBSA in the present study. Here, we report that the yield of the products depend both on the alkyl group of the reactants and on the surfactant.

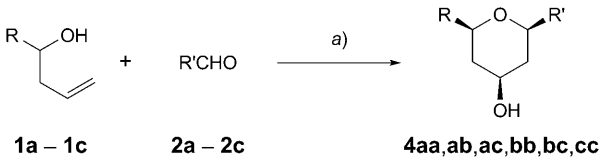
Results and Discussion. – In the present study, homoallyl alcohols **1a**–**1e** and aldehydes **2a**–**2j** were used as the substrates, among which **1b**–**1e** were prepared from the corresponding aldehydes **2b**–**2e** and allylmagnesium chloride (**3**) as shown in *Scheme 2*.

Scheme 2



Initially, the *Prins*-type reaction of **1a**–**1c** with aldehydes **2a**–**2c** was examined. The results are shown in *Scheme 3* and *Table 1*. The reaction of **1a** with benzaldehyde (**2a**) afforded only 4% of **4aa** after 3 days at room temperature, together with 87% of unreacted **1a** (*Entry 1*). Similarly, products were obtained in only low yield from either **1a** (*Entries 2* and *3*) or **2a** (*Entries 4* and *7*). The reaction proceeded with relatively better yields when both the homoallyl alcohol and the aldehyde have an aliphatic or alicyclic R (or R′) group (*Entries 5*, *6*, *8*, and *9*), among which the reaction of **1b** with cyclohexanecarboxaldehyde (**2b**) was the fastest, giving the product **4bb** in a good yield after a shorter reaction time (*Entry 5*). The data indicate that the three substituents can be ranked in the order cyclohexyl > $Me(CH_2)_6$ > Ph with respect to their product yields. For example, the order of the yields was **4bb** > **4bc** > **4ab** for both the reaction of **1b** (*Entries 4–6*) and that of **2b** (*Entries 2*, *5*, and *8*). The reaction was found to proceed slowly with a catalytic amount of DBSA (*Entry 10*).

Scheme 3



a) See text and *Table 1* for the conditions. See *Table 1* for the structure of each compound **4**.

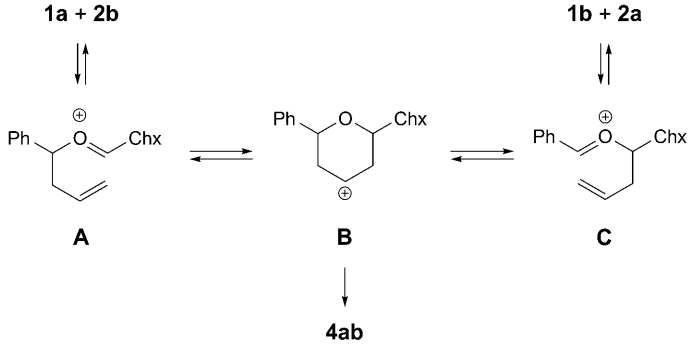
Table 1. *DBSA-Promoted Reactions of* **1a**–**1c** *with* **2a**–**2c** *in* H_2O[a])

Entry	Substrates	R[b])	R′[b])	Time [d]	Products (yield [%])[c])
1	**1a** + **2a**	Ph	Ph	3	**4aa** (4)
2	**1a** + **2b**	Ph	Chx	3	**4ab** (9), **4bb** (17)
3	**1a** + **2c**	Ph	$Me(CH_2)_6$	3	**4ac** (5), **4cc** (9)
4	**1b** + **2a**	Chx	Ph	3	**4ab** (43), **4bb** (5)
5	**1b** + **2b**	Chx	Chx	1	**4bb** (81)
6	**1b** + **2c**	Chx	$Me(CH_2)_6$	3	**4bc** (50), **4cc** (7)[d])
7	**1c** + **2a**	$Me(CH_2)_6$	Ph	3	**4ac** (23), **4cc** (4)
8	**1c** + **2b**	$Me(CH_2)_6$	Chx	2	**4bc** (55), **4bb** (9)[d])
9	**1c** + **2c**	$Me(CH_2)_6$	$Me(CH_2)_6$	3	**4cc** (61)
10[e])	**1b** + **2b**	Chx	Chx	1	**4bb** (20)

[a]) Reactions were carried out at r.t. with 100 mol-% of DBSA, except for *Entry 10*. Molar ratio **1**/**2** 1 : 1.5. [b]) Chx = cyclohexyl. [c]) Yield after isolation. [d]) The two products were not separated; the yields were determined based on the ^{1}H-NMR data of the mixture. [e]) 10 mol-% of DBSA was used.

From the reactions of **1a** + **2b** (*Entry 2*) and **1b** + **2a** (*Entry 4*), **4bb** was obtained as a by-product. Similarly, **4cc** was obtained from the reaction of both **1a** + **2c** (*Entry 3*) and **1c** + **2a** (*Entry 7*). This can be explained as follows. The reaction of **1a** and **2b** giving **4ab** proceeds through intermediate cations **A** and **B**, the latter of which is the same intermediate as generated from the reaction of **1b** and **2a** *via* **C** (*Scheme 4*). By the equilibration of **A**, **B**, and **C**, **1b** was generated *in situ* from the reaction of **1a** + **2b**, and similarly, **2b** was generated from the reaction of **1b** + **2a**. Since the reaction of **1b** and **2b** is faster, as described above, the resultant formation of **4bb** as the by-product was observed.

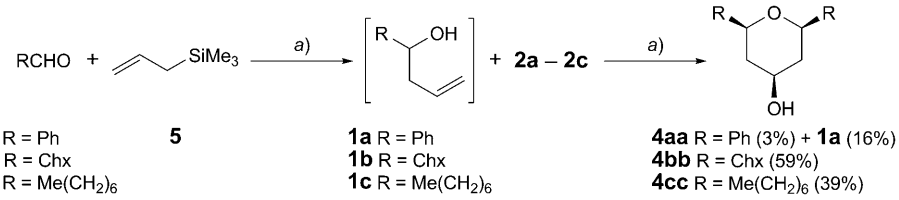
Scheme 4. *Expected Reaction Mechanism of the Formation of* **4ab**.



Since allylsilanes are the H_2O-stable carbanion equivalents, the reaction of aldehydes **2a**–**2c** and allyltrimethylsilane (**5**) was also carried out in H_2O in the presence of DBSA, expecting that **4** would be obtained together with **1** (*Scheme 5*). When benzaldehyde (**2a**) was treated with **5**, the reaction occurred slowly. After 3 weeks at room temperature, the expected product **1a** was isolated in only 16% yield, along with the 2 : 1 product **4aa** (3%). From cyclohexanecarboxaldehyde (**2b**) and

octanal (**2c**), the 1:1 reaction products **1b** and **1c** were not obtained, but only the 2:1 products **4bb** and **4cc** were isolated in 59 and 39% yield, respectively. These results indicate that the reaction of **1b** or **1c** with the corresponding aldehyde **2a** or **2b** was faster than that of **5**.

Scheme 5



a) See text for the conditions.

The reaction was further studied with various substrates, and the results are summarized in *Table 2*. When **1b** was reacted with **2d** or **2e**, the corresponding products, **4bd** and **4be**, were obtained as before (*Entries 1* and *2*). In contrast, the reactions with **2f**–**2j** were slow and afforded **4bf**–**4bj** in low yields, accompanying **4bb** as the by-product (*Entries 3–7*). These results, as well as the results listed in *Table 1*, suggest that conjugated aldehydes have low reactivity. No distinct difference was observed between the substituents $Me(CH_2)_6$ and $Me(CH_2)_{10}$ (*Entries 8*, *11*, and *12*), and not between the cyclohexyl and cyclopentyl groups either (*Entries 2*, *13*, and *14*).

Table 2. *DBSA-Promoted* Yadav*'s Reaction of Various Substrates*[a])

Entry	Substrates	R[b])	R′[b])	Time [d]	Products (yield [%])[c])
1	**1b** + **2d**	Chx	$Me(CH_2)_{10}$	3	**4bd** (69)
2	**1b** + **2e**	Chx	Cpe	1	**4be** (69)[d])
3	**1b** + **2f**	Chx	$Me(CH_2)_3CH(Et)$	3	**4bf** (36), **4bb** (15)[e])
4	**1b** + **2g**	Chx	cyclohex-1-en-1-yl	3	**4bg** (12), **4bb** (2)[e])
5	**1b** + **2h**	Chx	(*E*)-PrCH=CH	3	**4bh** (14), **4bb** (3)[e])
6	**1b** + **2i**	Chx	Me_2C=CH	3	**4bi** (25), **4bb** (3)[e])
7	**1b** + **2j**	Chx	$PhCH_2$	3	**4bj** (42), **4bb** (16)
8	**1c** + **2d**	$Me(CH_2)_6$	$Me(CH_2)_{10}$	3	**4cd** (54)
9	**1c** + **2e**	$Me(CH_2)_6$	Cpe	2	**4ce** (65), **4ee** (11)[e])
10	**1d** + **2b**	$Me(CH_2)_{10}$	Chx	3	**4bd** (49), **4bb** (9)[e])
11	**1d** + **2c**	$Me(CH_2)_{10}$	$Me(CH_2)_6$	3	**4cd** (60)
12	**1d** + **2d**	$Me(CH_2)_{10}$	$Me(CH_2)_{10}$	3	**4dd** (55)
13	**1e** + **2b**	Cpe	Chx	1	**4be** (78)[d])
14	**1e** + **2e**	Cpe	Cpe	1	**4ee** (80)

[a]) Reactions were carried out at r.t. with 100 mol-% of DBSA. Molar ratio **1**/**2** 1:1.5. [b]) Chx = cyclohexyl, Cpe = cyclopentyl. [c]) Isolated yield. [d]) **4bb** and **4ee** were detected by GC, but their amounts were not determined. [e]) The two products were not separated; the yields were determined based on the ^{1}H-NMR data of the mixture.

To evaluate the effect of the aromatic ring in DBSA, the reactions were carried out in the presence of SDS (sodium dodecyl sulfate) and HCl with homoallyl alcohols and

aldehydes having the same alkyl substituent (R = R′; *Table 3*). An interesting result was obtained, namely, the reaction was obviously faster in SDS/HCl than in DBSA (cf. *Tables 1* and *2*) when the alkyl group was $Me(CH_2)_6$ and $Me(CH_2)_{10}$ (*Entries 3–5*). In contrast, no difference in surfactant was observed for the cycloalkyl substituents (*Entries 1*, *2*, and *6*).

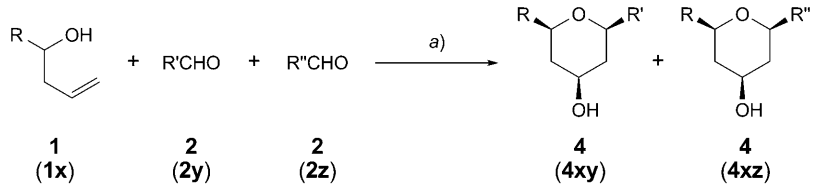
Table 3. *Reactions of* **1b**–**1e** *with* **2b**–**2e** *in SDS/HCl*[a])

Entry	Substrates	R = R′[b])	HCl [equiv.]	Time [d]	Products (yield [%])[c])
1	**1b** + **2b**	Chx	1.0	1	**4bb** (74)
2	**1b** + **2b**	Chx	2.0	1	**4bb** (79)
3	**1c** + **2c**	$Me(CH_2)_6$	1.0	2	**4cc** (52)
4	**1c** + **2c**	$Me(CH_2)_6$	2.0	1	**4cc** (64)
5	**1d** + **2d**	$Me(CH_2)_{10}$	2.0	2	**4dd** (58)
6	**1e** + **2e**	Cpe	2.0	1	**4ee** (78)

[a]) All the reactions were carried out in H_2O at r.t. with 100 mol-% of SDS (sodium dodecyl sulfate). Molar ratio **1**/**2** 1 : 1.5. [b]) Chx = cyclohexyl, Cpe = cyclopentyl. [c]) Yield of isolated products.

To confirm the above results, two aldehydes were treated competitively with a single homoallyl alcohol (*Scheme 6* and *Table 4*). It was shown again that the nonaromatic surfactant is favored for the substrate having an unbranched alkyl substituent. Namely, the proportion of **4cc** over **4bc** was obviously higher for the reaction of **1c** in SDS/HCl (*Entries 7* and *8*) than in DBSA (*Entries 5* and *6*), while only a small surfactant effect was observed for the reaction of **1b** (*Entries 1–4*). Similarly, the proportion of **4cc** over **4ce** was higher for the reaction of **1c** in SDS/HCl than in DBSA (*Entries 11–13*), but not for **1e** (*Entries 9* and *10*). Probably, the product ratio of *ca.* 6 : 4 is the 'original value' for both **2b**/**2c** and **2e**/**2c**. The higher ratio in the DBSA-promoted reaction of **1c** (*Entries* 5, *6*, and *11*) can be rationalized by the inference that the reaction **1c** + **2c** was less favorable in DBSA, however, the reason is not clear as yet. The result is consistent with the observation described for *Table 1*.

Scheme 6



a) See text and *Table 4* for the conditions.

In conclusion, it was found that an alkyl-substituent effect is surely present in the aqueous reaction of a homoallyl alcohol with an aldehyde (*Yadav*'s reaction system), although the effect was not dramatic. The reaction proceeded smoothly for non-conjugated aldehydes, and the compounds with structurally related substituents such as $Me(CH_2)_6$ and $Me(CH_2)_{10}$, as well as cyclopentyl and cyclohexyl, showed similar

Table 4. *Competition of Aldehydes Against Single Homoallyl Alcohol*[a])

Entry	Alcohol	Aldehyde[b])	Surfactant	Time [d]	Yield [%][c])	Ratio
1	**1b** (R = Chx)	**2b** and **2c**	DBSA[d])	1	63	**4bb**/**4bc** 62 : 38
2	**1b** (R = Chx)	**2b** and **2c**	DBSA[e])	1	64	**4bb**/**4bc** 62 : 38
3	**1b** (R = Chx)	**2b** and **2c**	SDS/HCl[f])	1	54	**4bb**/**4bc** 58 : 42
4	**1b** (R = Chx)	**2b** and **2c**	SDS/HCl[g])	1	61	**4bb**/**4bc** 57 : 43
5	**1c** (R = $Me(CH_2)_6$)	**2b** and **2c**	DBSA[d])	2	54	**4bc**/**4cc** 85 : 15
6	**1c** (R = $Me(CH_2)_6$)	**2b** and **2c**	DBSA[e])	2	39	**4bc**/**4cc** 75 : 25
7	**1c** (R = $Me(CH_2)_6$)	**2b** and **2c**	SDS/HCl[f])	2	56	**4bc**/**4cc** 54 : 46
8	**1c** (R = $Me(CH_2)_6$)	**2b** and **2c**	SDS/HCl[g])	1	58	**4bc**/**4cc** 56 : 44
9	**1e** (R = Cpe)	**2e** and **2c**	DBSA[d])	1	59	**4ee**/**4ce** 64 : 36
10	**1e** (R = Cpe)	**2e** and **2c**	SDS/HCl[g])	1	68	**4ee**/**4ce** 58 : 42
11	**1c** (R = $Me(CH_2)_6$)	**2e** and **2c**	DBSA[d])	2	35	**4ce**/**4cc** 85 : 15
12	**1c** (R = $Me(CH_2)_6$)	**2e** and **2c**	SDS/HCl[f])	2	37	**4ce**/**4cc** 67 : 33
13	**1c** (R = $Me(CH_2)_6$)	**2e** and **2c**	SDS/HCl[g])	1	50	**4ce**/**4cc** 64 : 36

[a]) All reactions were carried out in H_2O at r.t. [b]) 1.2 Equiv. of each aldehyde was used. [c]) Yield of isolated products. [d]) 100 mol-%. [e]) 200 mol-%. [f]) 100 mol-% of SDS with 1.0 equiv. of HCl. [g]) 100 mol-% of SDS with 2.0 equiv. of HCl.

behavior, as expected. When both of the two reactants, the homoallyl alcohol and the aldehyde, have an unbranched alkyl group, the reaction was more favorable in SDS/HCl than in DBSA. These observations suggest that the structural similarity is a factor determining the reactivity. We hope that the present results will be helpful in the various studies of aqueous organic reactions.

Experimental Part

General. Anh. Na_2SO_4 was used for drying the extracted org. layers. Anal. TLC: precoated TLC plates (silica gel *60* F_{254}, layer thickness 0.2 mm). Column chromatography (CC): *Wakogel C-200* or *Florisil* (100–200 mesh). M.p.: *Laboratory-Devices-Mel-Temp* apparatus. IR Spectra: *Jasco-FT/IR-230* spectrometer; $\tilde{\nu}$ in cm^{-1}. ^1H- and ^{13}C-NMR Spectra: *Jeol-GSX-400* spectrometer; 400 MHz for ^1H and 100 MHz for ^{13}C; $CDCl_3$ solns.; chemical shifts δ in ppm with Me_4Si (for ^1H) or solvent (δ ($CDCl_3$) 77.00 for ^{13}C) as internal standard, unless otherwise noted, *J* in Hz. EI-MS and HR-EI-MS: *Jeol-SX-102A*, *CMATE-II*, or *Shimadzu-GCMS-QP5050* mass spectrometer; in *m*/*z* (rel. %).

Preparation of the Substrates. Compound **1a** is commercially available. Compounds **1b**–**1e** were synthesized as follows. A soln. of commercial allylmagnesium chloride (**3**; 2.5 ml, 5 mmol; 2.0M in THF) was diluted with dry Et_2O (20 ml), and aldehyde **2** (5 mmol) was added at $-50°$. After being stirred for 4 h, the mixture was slowly warmed to r.t. overnight. Then, a sat. aq. NH_4Cl soln. was added, the mixture extracted with Et_2O, the org. layer dried and concentrated, and the resultant oily residue subjected to CC (SiO_2) to afford homoallyl alcohols **1b**–**1e**.

Typical Procedure of Yadav*'s Reaction.* Aldehyde **2** (1.50 mmol) was added to a stirred mixture of homoallyl alcohol **1** (1.00 mmol) and 4-dodecylbenzenesulfonic acid (1.00 mmol) in H_2O (10 ml). After being stirred at r.t. for 1–3 day(s) (see *Tables 1–4*), an aq. sat. $NaHCO_3$ soln. was added, the mixture extracted with Et_2O, the org. layer dried and concentrated, and the residue purified by CC (SiO_2) to afford the product(s).

Compounds **4bc**, **4be**, **4bf**, **4bg**, **4bh**, **4bi**, and **4ce** could not be isolated in pure form due to the presence of inseparable by-product(s), and the following spectral data were obtained after partial purification. Compounds **4aa** [4], **4ab** [4], and **4bb** [6] were identified by comparison with the literature data.

*(2*RS*,4*SR*,6*RS*)-2-Heptyltetrahydro-6-phenyl-2*H*-pyran-4-ol* (**4ac**): Colorless oil. IR (neat): 3383 (OH). ^{1}H-NMR: 0.88 (*t*, *J* = 6.9, 3 H); 1.21–1.72 (*m*, 14 H); 1.83 (br., OH); 2.02 (*ddt*, *J* = 12.1, 4.6, 2.0, 1 H); 2.20 (*ddt*, *J* = 12.1, 4.5, 2.1, 1 H); 3.44–3.51 (*m*, 1 H); 3.94 (*tt*, *J* = 11.0, 4.6, 1 H); 4.35 (*dd*, *J* = 11.5, 1.9, 1 H); 7.24–7.38 (*m*, 5 H). ^{13}C-NMR: 14.10; 22.65; 25.48; 29.24; 29.62; 31.83; 36.04; 40.90; 42.98; 68.69; 76.01; 77.26; 125.87 (2C); 127.37; 128.32 (2C); 142.26. EI-MS: 276 (6, M^+), 258 (5), 159 (33), 107 (100).

*(2*RS*,4*SR*,6*RS*)-2-Cyclohexyl-6-heptyltetrahydro-2*H*-pyran-4-ol* (**4bc**): Colorless oil. IR (neat): 3357 (OH). ^{1}H-NMR: 0.88 (*t*, *J* = 6.9, 3 H); 0.92–1.76 (*m*, 23 H); 1.88–2.01 (*m*, 4 H); 2.06 (br., OH); 2.89–2.98 (*m*, 1 H); 3.16–3.26 (*m*, 1 H); 3.74 (*tt*, *J* = 11.0, 4.8, 1 H). ^{13}C-NMR: 14.06; 22.61; 25.66; 25.98; 26.13; 26.55; 28.77; 29.24; 29.37; 29.48; 31.82; 36.06; 38.28; 41.53; 42.70; 68.81; 75.45; 79.93. EI-MS: 199 (36, [M – cyclohexyl]$^+$), 183 (10), 155 (29), 139 (24), 41 (100). FAB-HR-MS: 283.2651 ([M + H]$^+$, $C_{18}H_{35}O_2^+$; calc. 283.2637).

*(2*RS*,4*SR*,6*RS*)-2-Cyclohexyltetrahydro-6-undecyl-2*H*-pyran-4-ol* (**4bd**): White solid. M.p. 53.5–55.5°. IR (KBr): 3340 (OH). ^{1}H-NMR: 0.88 (*t*, *J* = 6.8, 3 H); 0.91–1.76 (*m*, 31 H); 1.88–2.01 (*m*, 4 H); 2.05 (br., OH); 2.89–2.98 (*m*, 1 H); 3.16–3.26 (*m*, 1 H); 3.75 (*tt*, *J* = 11.0, 4.7, 1 H). ^{13}C-NMR: 14.08; 22.65; 25.67; 25.99; 26.14; 26.56; 28.78; 29.32; 29.38; 29.52; 29.60 (3C); 29.63; 31.89; 36.06; 38.30; 41.55; 42.71; 68.85; 75.45; 79.93. EI-MS: 183 (28, [M – $C_{11}H_{23}$]$^+$), 165 (17), 139 (100). FAB-HR-MS: 339.3247 ([M + H]$^+$, $C_{22}H_{43}O_2^+$; calc. 339.3263).

*(2*RS*,4*SR*,6*SR*)-2-Cyclohexyl-6-cyclopentyltetrahydro-2*H*-pyran-4-ol* (**4be**): White solid. M.p. 100.0–102.0°. IR (KBr): 3294 (OH). ^{1}H-NMR: 0.88–2.04 (*m*, 25 H); 2.90–3.00 (*m*, 2 H); 3.74 (*tt*, *J* = 10.9, 4.6, 1 H). ^{13}C-NMR: 25.52; 25.62; 26.01; 26.18; 26.62; 28.95; 28.97; 29.35; 29.41; 38.55; 40.48; 42.78; 45.23; 69.05; 79.94; 80.03. EI-MS: 183 (18, [M – cyclopentyl]$^+$), 169 (15, [M – cyclohexyl]$^+$), 165 (9), 139 (54), 125 (100).

*(2*RS*,4*SR*,6*SR*)-2-Cyclohexyl-6-(1-ethylpentyl)tetrahydro-2*H*-pyran-4-ol* (**4bf**; 1:1 mixture of two diastereoisomers). Colorless oil. IR (neat): 3338 (OH). ^{1}H-NMR: 0.85 (*t*, *J* = 6.8, 1.5 H, Me); 0.86 (*t*, *J* = 6.8, 1.5 H, Me); 0.89 (*t*, *J* = 6.9, 3 H, Me); 0.93–1.48 (*m*, 16 H); 1.61–1.78 (*m*, 4 H); 1.90–1.98 (*m*, 4 H); 2.30 (br., OH); 2.90–2.99 (*m*, 1 H); 3.09–3.17 (*m*, 1 H); 3.75 (*tt*, *J* = 10.9, 4.8, 1 H). ^{13}C-NMR: 10.80; 11.41; 14.08; 14.13; 21.83; 22.28; 23.09; 23.20; 26.07 (2C); 26.20 (2C); 26.62 (2C); 28.65 (2C); 28.91; 28.93; 29.06; 29.08 (2C); 29.16; 38.29; 38.41; 38.45 (2C); 42.77; 42.80; 43.75; 44.06; 69.44 (2C); 77.08; 77.15; 79.84; 79.86. EI-MS: 199 (2, [M – cyclohexyl]$^+$), 183 (26, [M – Me(CH$_2$)$_3$CH(Et)]$^+$), 165 (15), 139 (100). FAB-HR-MS: 283.2594 ([M + H]$^+$, $C_{18}H_{35}O_2^+$; calc. 283.2637).

*(2*RS*,4*SR*,6*SR*)-2-(Cyclohex-1-en-1-yl)-6-cyclohexyltetrahydro-2*H*-pyran-4-ol* (**4bg**): White solid. M.p. 58.5–60.5°. IR (neat): 3361 (OH). ^{1}H-NMR: 0.80–2.28 (*m*, 24 H); 3.07 (*ddd*, *J* = 11.2, 6.5, 1.4, 1 H); 3.58 (*d*, *J* = 11.2, 1 H); 3.81 (*tt*, *J* = 10.9, 4.7, 1 H); 5.69 (br. *s*, 1 H). ^{13}C-NMR: 22.48; 22.61; 24.91; 25.24; 26.13; 26.19; 26.62; 28.56; 29.27; 37.88; 39.53; 42.73; 69.19; 78.59; 79.82; 121.86; 137.95. EI-MS: 264 (14, M^+), 181 (2, [M – cyclohexyl]$^+$), 139 (66), 121 (100). HR-EI-MS: 264.2086 (M^+, $C_{17}H_{28}O_2^+$; calc. 264.2089).

*(2*RS*,4*RS*,6*SR*)-2-Cyclohexyltetrahydro-6-[(1*E*)-pent-1-en-1-yl]-2*H*-pyran-4-ol* (**4bh**): Colorless oil. IR (neat): 3365 (OH). ^{1}H-NMR: 0.89 (*t*, *J* = 7.2, 3 H); 0.90–2.04 (*m*, 20 H); 3.07 (*ddd*, *J* = 11.1, 6.5, 1.3, 1 H); 3.70–3.76 (*m*, 1 H); 3.79 (*tt*, *J* = 11.0, 4.7, 1 H); 5.50 (br. *dd*, *J* = 15.3, 5.8, 1 H); 5.66 (br. *dt*, *J* = 15.3, 6.5, 1 H). ^{13}C-NMR: 13.70; 22.19; 26.11; 26.17; 26.57; 28.50; 29.44; 34.39; 37.68; 41.62; 42.66; 68.76; 75.91; 79.86; 130.46; 131.72. EI-MS: 183 (23, [M – PrCH=CH]$^+$), 139 (79), 55 (100). HR-EI-MS: 252.2071 (M^+, $C_{16}H_{28}O_2^+$; calc. 252.2089).

*(2*RS*,4*RS*,6*SR*)-2-Cyclohexyltetrahydro-6-(2-methylprop-1-en-1-yl)-2*H*-pyran-4-ol* (**4bi**): Yellow oil. IR (neat): 3359 (OH). ^{1}H-NMR: 0.88–1.49 (*m*, 11 H); 1.61–1.99 (*m*, 5 H); 1.67 (*d*, *J* = 0.9, 3 H); 1.72 (br. *s*, 3 H); 3.06 (*ddd*, *J* = 11.2, 6.6, 1.6, 1 H); 3.79 (*tt*, *J* = 10.9, 4.7, 1 H); 3.96 (*ddd*, *J* = 11.2, 7.5, 1.7, 1 H); 5.20 (*d*·*sept.*, *J* = 7.5, 1.2, 1 H). ^{13}C-NMR: 18.43; 25.69; 26.05; 26.12; 26.54; 28.45; 29.50; 37.60; 41.61; 42.58; 68.70; 72.59; 79.91; 125.50; 136.28. EI-MS: 238 (3, M^+), 139 (20), 41 (100). HR-EI-MS: 238.1947 (M^+, $C_{15}H_{26}O_2^+$; calc. 238.1933).

*(2*RS*,4*SR*,6*RS*)-2-Cyclohexyltetrahydro-6-(phenylmethyl)-2*H*-pyran-4-ol* (**4bj**): White solid. M.p. 97.5–101.5°. IR (KBr): 3303 (OH). ^{1}H-NMR: 0.88–1.45 (*m*, 8 H); 1.62–1.75 (*m*, 5 H); 1.85–1.97 (*m*, 3 H); 2.67 (*dd*, *J* = 13.5, 6.3, 1 H); 2.95 (*dd*, *J* = 13.6, 6.5, 1 H); 2.99 (*ddd*, *J* = 11.3, 6.7, 1.6, 1 H); 3.43 (*ddt*, *J* = 11.0, 1.7, 6.4, 1 H); 3.69 (*tt*, *J* = 10.9, 4.7, 1 H); 7.17–7.29 (*m*, 5 H). ^{13}C-NMR: 26.07; 26.17; 26.56; 28.76;

29.14; 37.96; 40.76; 42.44; 42.70; 68.71; 76.29; 79.88; 126.07; 128.08 (2C); 129.44 (2C); 138.59. EI-MS: 183 (48, $[M - PhCH_2]^+$), 165 (14), 139 (100).

*(2α,4α,6α)-2,6-Diheptyltetrahydro-2*H*-pyran-4-ol* (**4cc**): White solid. M.p. 58.0–59.5°. IR (KBr): 3460 (OH). ^{1}H-NMR: 0.88 (*t*, *J* = 6.8, 6 H); 1.12 (*dt*, *J* = 12.2, 11.1, 2 H); 1.23–1.47 (*m*, 22 H); 1.53–1.60 (*m*, 2 H); 1.75 (br., OH); 1.93 (br. *dd*, *J* = 12.0, 4.5, 2 H); 3.19–3.27 (*m*, 2 H); 3.77 (*tt*, *J* = 10.9, 4.7, 1 H). ^{13}C-NMR: 14.08 (2C); 22.64 (2C); 25.69 (2C); 29.28 (2C); 29.51 (2C); 31.82 (2C); 36.08 (2C); 41.43 (2C); 68.50; 75.53 (2C). EI-MS: 199 (55, $[M - C_7H_{15}]^+$), 181 (13), 163 (36), 41 (100).

*(2*RS*,4*SR*,6*SR*)-2-Heptyltetrahydro-6-undecyl-2*H*-pyran-4-ol* (**4cd**): White solid. M.p. 55.5–58.0°. IR (KBr): 3462 (OH). ^{1}H-NMR: 0.88 (*t*, *J* = 6.8, 6 H); 1.12 (*dt*, *J* = 12.0, 11.2, 2 H); 1.23–1.45 (*m*, 30 H); 1.53–1.60 (*m*, 2 H); 1.85 (br., OH); 1.93 (*dd*, *J* = 12.0, 4.5, 2 H); 3.19–3.26 (*m*, 2 H); 3.77 (*tt*, *J* = 10.9, 4.8, 1 H). ^{13}C-NMR: 14.08; 14.09; 22.64; 22.66; 25.68 (2C); 29.28; 29.34; 29.52; 29.56; 29.61 (3C); 29.66; 31.82; 31.90; 36.08 (2C); 41.42 (2C); 68.47; 75.54 (2C). EI-MS: 199 (44, $[M - C_{11}H_{23}]^+$), 181 (14), 163 (35), 55 (100).

*(2*RS*,4*SR*,6*RS*)-2-Cyclopentyl-6-heptyltetrahydro-2*H*-pyran-4-ol* (**4ce**): Colorless oil. IR (neat): 3348 (OH). ^{1}H-NMR: 0.88 (*t*, *J* = 6.8, 3 H); 1.08–2.02 (*m*, 26 H); 2.94–3.01 (*m*, 1 H); 3.18–3.25 (*m*, 1 H); 3.76 (*tt*, *J* = 10.9, 4.7, 1 H). ^{13}C-NMR: 14.07; 22.63; 25.42; 25.51; 25.73; 28.92; 29.27; 29.47; 29.49; 31.82; 36.06; 40.30; 41.56; 45.16; 68.62; 75.48; 80.06. EI-MS: 199 (19, $[M$ – cyclopentyl$]^+$), 181 (8), 169 (7, $[M - C_7H_{15}]^+$), 163 (24), 81 (86), 41 (100).

*(2α,4α,6α)-Tetrahydro-2,6-diundecyl-2*H*-pyran-4-ol* (**4dd**): White solid. M.p. 79.0–80.5°. IR (KBr): 3454 (OH). ^{1}H-NMR: 0.88 (*t*, *J* = 6.8, 6 H); 1.12 (*q*, *J* = 11.3, 2 H); 1.23–1.45 (*m*, 39 H); 1.52–1.61 (*m*, 2 H); 1.94 (br. *dd*, *J* = 12.0, 4.4, 2 H); 3.19–3.27 (*m*, 2 H); 3.78 (*tt*, *J* = 10.9, 4.7, 1 H). ^{13}C-NMR: 14.11 (2C); 22.68 (2C); 25.70 (2C); 29.35 (2C); 29.57 (2C); 29.62 (4C); 29.64 (2C); 29.67 (2C); 31,92 (2C); 36.09 (2C); 41.46 (2C); 68.54; 75.53 (2C). EI-MS: 255 (12, $[M - C_{11}H_{23}]^+$), 237 (5), 199 (27), 163 (20), 43 (100).

*(2α,4α,6α)-2,6-Dicyclopentyltetrahydro-2*H*-pyran-4-ol* (**4ee**): White solid. M.p. 118.5–120.0°. IR (KBr): 3336 (OH). ^{1}H-NMR: 1.13 (*dt*, *J* = 12.3, 11.2, 2 H); 1.13–1.23 (*m*, 2 H); 1.35–1.73 (*m*, 13 H); 1.77–1.86 (*m*, 2 H); 1.89 (*q*, *J* = 7.9, 2 H); 1.96–2.02 (*m*, 2 H); 2.97 (*ddd*, *J* = 11.0, 7.9, 1.5, 2 H); 3.75 (*tt*, *J* = 11.0, 4.7, 1 H). ^{13}C-NMR: 25.52 (2C); 25.63 (2C); 29.00 (2C); 29.42 (2C); 40.44 (2C); 45.18 (2C); 68.83; 80.01 (2C). EI-MS: 169 (16, $[M$ – cyclopentyl$]^+$), 151 (6), 125 (100). HR-EI-MS: 238.1969 (M^+, $C_{15}H_{26}O_2^+$; calc. 238.1933).

Reaction of **2** *and* **5**. Allyltrimethylsilane (**5**; 15 mmol) was added to a mixture of aldehyde **2** (5 mmol) and 4-dodecylbenzenesulfonic acid (5 mmol) in H_2O (35 ml). After being stirred at r.t. for 3 weeks, the mixture was extracted with Et_2O, the org. layer dried and concentrated, and the residue purified by CC (SiO_2) to give **4**.

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