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Chemoenzymatic synthesis of enantiomerically pure alkene 1,2-diols and glycosides thereof

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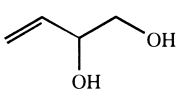
Abstract

The kinetic resolution of racemic 2-*O*-acylated 3-butene-1,2-diol and 1-*O*-acylated 3-butene-1,2-diol derivatives by enzymatic saponification and enzymatic esterification, respectively, is investigated with several lipases and esterases. The resulting partially blocked enantiomers are glycosylated with glycosyl halides and trichloroacetimidates, respectively.

1. Introduction

Due to their multifunctional character, enantiomerically pure alkene diols are important building blocks for a wide variety of stereoselective transformations. For example, enantiomerically pure 3-butene-1,2-diols have been used for aminosugar syntheses via isoxazolines[1,2] and for the synthesis of optically active precursors for the preparation of HIV protease inhibitors[3] or cyclosporins.[4] Similarly, enantiomerically pure 4-pentene-1,3-diols were successfully applied for the synthesis of deoxyfuranosides[5,6] and deoxypyranosides.[7] Furthermore, cycloalkenyl diols and dihydroxy-α,ω-dienes were shown to be useful precursors for asymmetric C–C bond formations by aldolase catalysis.[8] As part of a project for the chemoenzymatic synthesis of novel non-natural saccharides we were interested in simple *O*-glycosides of enantiomerically pure alkene diols **1**–**4**. For that purpose, efficient procedures were needed for the preparation of both enantiomers of suitably protected derivatives of diols **1**–**4** which allow glycosylation of the primary and secondary alcohol function, respectively.



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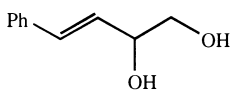

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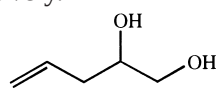

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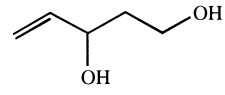

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Enantiomerically enriched derivatives of 3-butene-1,2-diols **1** and **2** have previously been obtained by Wittig olefination of (*S*)-isopropylidene glyceraldehyde[4,9–11] and by kinetically controlled Sharpless epoxidation of 1-benzyloxy-3-butene-2-ol[4,12] or 1-tosyloxy-3-butene-2-ol.[13] Optically active derivatives related to diols **3** and **4** were previously prepared by addition of chiral allyl boranes to glycol aldehyde[14] or by reduction of chiral ethyl 3-hydroxy-4-pentenoate, respectively.[15] However, for the economical preparation of both enantiomers, kinetic resolution of racemic derivatives of **1**–**4** by lipases and esterases appeared to be especially useful. For example, 1-silyloxy-2-chloroacetoxy-3-butenes have been recently used for enzymatic saponification by *Pseudomonas fluorescens* esterases with high selectivities (E>100).[16] Similarly, *Pseudomonas* lipase-catalyzed esterification of 1-tosyloxy-3-butene-2-ol with vinyl acetate in organic solvents also resulted in excellent selectivities (E>200)[17]. Here, we wish to describe practical preparations and kinetic resolutions of racemic derivatives of diols **1** and **2** by several esterases and lipases as well as their subsequent glycosylation.

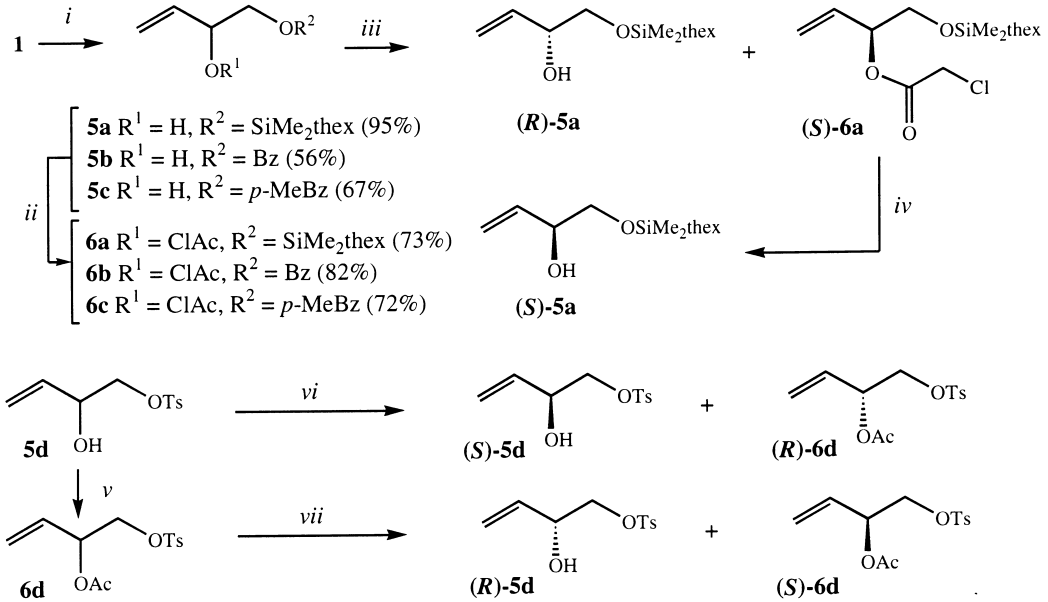
2. Results and discussion

Previously, enzymatic saponifications of chloroacetylated 3-butene-1,2-diols having position 1 blocked by a bulky group (i.e. dimethylthexylsilyl and dimethyl-*tert*-butylsilyl, respectively)[16] have been shown to be highly effective. Therefore, a series of racemic 1-protected 3-butene-2-yl acetates and chloroacetates **6** were first prepared from 3-butene-1,2-diol[18] as outlined in Scheme 1 and tested as substrates in enzymatic saponifications with several lipases and esterases (Table 1). Compounds **6a**–**d** were chosen because enzymatic saponifications led to products **5** which appeared to be suitable glycosyl acceptors for direct glycosylation reactions. In general, the best enantioselectivities (E>300) were obtained for the dimethylthexylsilyl-protected derivative **6a**, as previously described,[16] under catalysis by *Pseudomonas* lipase (Table 1, entry 1). Of the enzymes tested, only the lipases from *Candida antarctica* (entry 3) and *Humicola* sp. (entry 9) also gave useful results (E>100) with substrate **6a**. The 1-*O*-acyl-protected substrates **6b** and **6c** did not show any discrimination of the enantiomers by enzymatic saponification (entries 10 and 11). Therefore, racemic **6a** was chosen for *Pseudomonas* lipase-catalyzed saponification on a preparative scale (27 g) to afford (*R*)-**5a** (97% ee) in 47% yield and (*S*)-**6a** (99% ee) in 45% yield, respectively. Finally, lipase from *Candida cylindracea* which has been shown to act completely unselectively for substrate **6a** (entry 4), was used for the chemoselective removal of the chloroacetyl group in (*S*)-**6a**, to give (*S*)-**5a** in 85% yield.

It should be noted that the enzymatic cleavage of the chloroacetyl group with *C. cylindracea* lipase was superior to the corresponding chemical removal with thiourea which afforded (*S*)-**5a** in 24% yield. Both enantiomers (*R*)-**5a** and (*S*)-**5a** were subsequently benzoylated to give first the corresponding fully blocked derivatives **7** (Scheme 2). Next, the silyl group was removed with $BF_3 \cdot Et_2O$ in methanol[19] to afford the enantiomers **8** accompanied by the products of transesterification **5b**. Enantiomers (*R*)-**8** and (*S*)-**8** are useful acceptors for the direct glycosylation of position 1 which will be reported elsewhere.

For *p*-methylbenzenesulfonate-protected diol **6d**, enantioselective lipase catalyzed saponification was completely ineffective when a chloroacetyl group was present instead of an acetate (details not shown here). Thus, 2-acetoxy-3-butene-1-yl *p*-methylbenzenesulfonate **6d** was used in combination with *Pseudomonas* lipase (Table 1, entry 12) to afford (*R*)-**5d** (99% ee) in 41% yield and (*S*)-**6d** (99% ee) in 44% yield, respectively on a 7 g scale. In order to prepare both enantiomers of compound **5d** — suitable for direct glycosylation of position 2 — racemic **5d** was enzymatically acetylated as previously described[17] to give (*S*)-**5d** and (*R*)-**6d**, respectively.

Next, compounds (*R*)-**5a** and (*R*)-**5d** were used as glycosyl acceptors. Condensation of (*R*)-**5a** with



Scheme 1. (i) **5a**, Cl–$SiMe_2$thex, imidazole, CH_2Cl_2, 0°C, 90 min; **5b**, BzCl, pyridine, −35°C, 17 h; **5c**, *p*-MeBzCl, pyridine, −15°C, 15 h. (ii) **6a**, chloroacetic anhydride ($ClAc_2O$), pyridine, −10°C, 1 h; **6b**, $ClAc_2O$, pyridine, 0°C, 2 h; **6c**, $ClAc_2O$, pyridine, 0°C, 1 h. (iii) Enzyme, phosphate buffer (pH 7.0), rt, (Table 1). (iv) *Candida cylindracea*, phosphate buffer (pH 7.0), rt, 4 days, 87%. (v) Acetic anhydride, pyridine, rt, 4 h, 93%. (vi) Literature.[17] (vii) *Pseudomonas* lipase, phosphate buffer (pH 7.0), 2 h 45 min (Table 1)

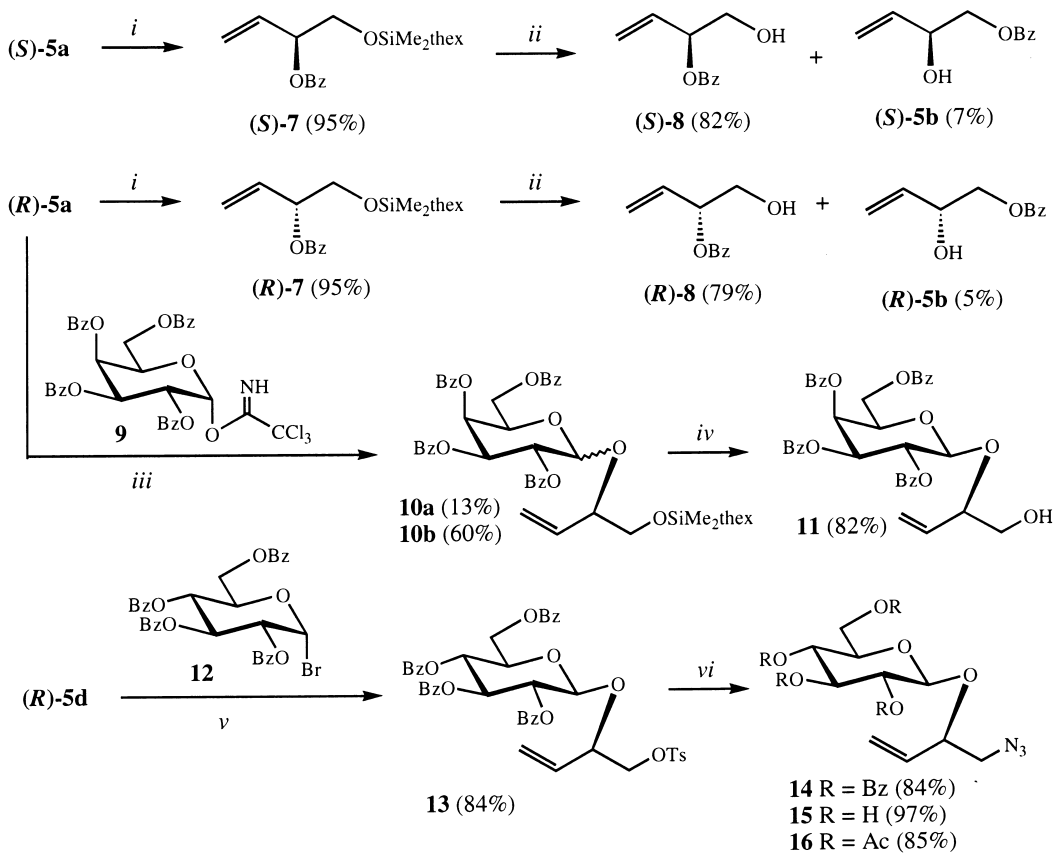
Table 1
Enzymatic saponification of **6a–d** by several lipases and esterases[a]

entry	enzyme	substrate	conversion	time	products (ee) alcohol **5**	ester **6**	E-value
1	*Pseudomonas sp.*[b]	**6a**	50.2%	8.5 h	(***R***)-**5a** (97%)	(***S***)-**6a** (99%)	348
2	*Pseudomonas sp.*[c,d]	**6a**	50.4%	19.5 h	(***R***)-**5a** (88%)	(***S***)-**6a** (96%)	61
3	*Candida antarctica B*[c]	**6a**	49.2%	13.7 h	(***R***)-**5a** (94%)	(***S***)-**6a** (95%)	121
4	*Candida cycindracea*[c]	**6a**	97.9%	22.0 h	-	-	-
5	*Pseudomonas sp.*[c,e]	**6a**	52.0%	26.0 h	(***R***)-**5a** (7%)	(***S***)-**6a** (10%)	1.3
6	*Candida antarctica* A[c]	**6a**	70.3%	12.5 h	(***R***)-**5a** (14%)	(***S***)-**6a** (94%)	3.5
7	*Pseudomonas sp.*[c]	**6a**	65.0%	12.0 h	(***R***)-**5a** (29%)	(***S***)-**6a** (78%)	3.9
8	Porcine pancreas lip.[c]	**6a**	53.5%	35.0 h	(***R***)-**5a** (72%)	(***S***)-**6a** (75%)	14
9	*Humicola sp.*[c]	**6a**	54.5%	91.0 h	(***R***)-**5a** (94%)	(***S***)-**6a** (97%)	136
10	*Pseudomonas sp.*[b]	**6b**	100%	2.75 h	-	-	-
11	*Pseudomonas sp.*[b]	**6c**	100%	2.75 h	-	-	-
12	*Pseudomonas sp.*[b]	**6d**	50.0%	2.75 h	(***R***)-**5d** (99%)	(***S***)-**6d** (99%)	1057

[a] The saponification was monitored *via* consumption of base and stopped when consumption of base significantly slowed down; [b] Amano PS lipase; [c] Boehringer Mannheim GmbH, CHIRAZYM®; [d] related to *Burkholderia cepacia*; [e] cholesterol esterase.

galactosyl trichloroacetimidate[20] **9** gave first the corresponding D-galactopyranosides **10a** and **10b**, respectively. Desilylation of the β-galactoside **10b** then afforded crystalline galactoside **11** (Scheme 2). Similarly, alcohol (*R*)-**5d** was glucosylated with benzobromoglucose **12** under promotion with silver trifluoromethanesulfonate to give glucoside **13** which served as a precursor for further introduction of functional groups. For example, treatment of **13** with NaN_3 gave **14**, which was converted via **15** into crystalline **16**. For both glycosides **11** and **16**, respectively, the X-ray structure[21] showed unambiguously the (*R*)-configuration of the aglycons.

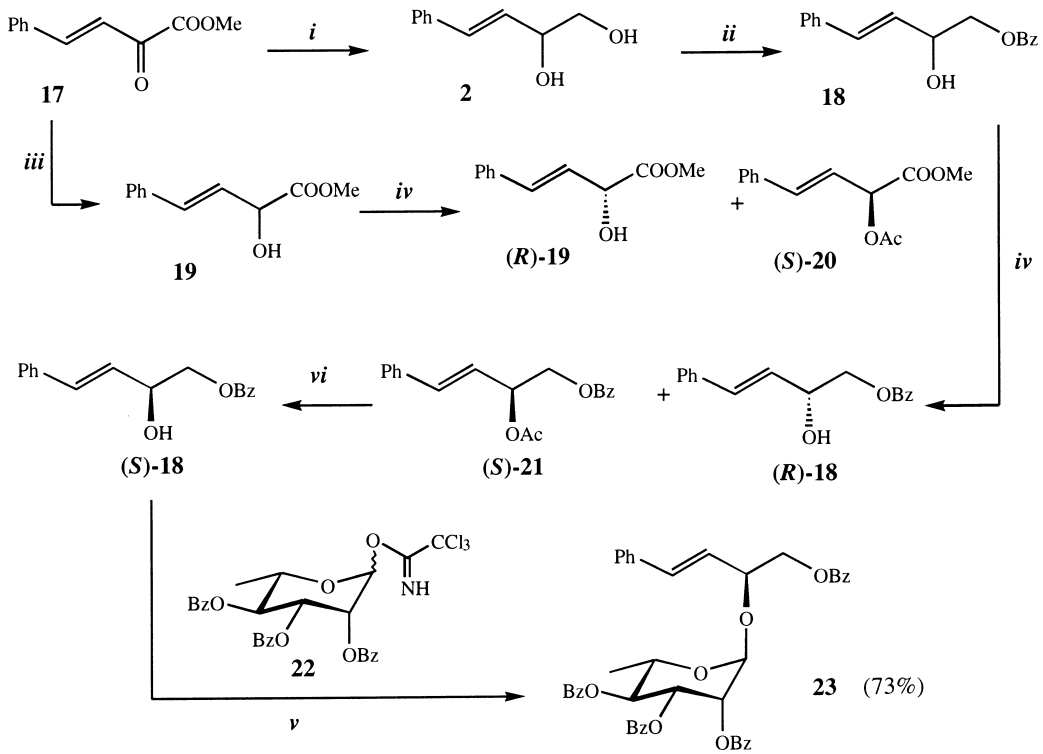
4-Phenyl-*E*-3-butene-1,2-diol **2**[22,23] was another diol which was tested for enzymatic preparation



Scheme 2. (i) BzCl, pyridine, rt, 17 h. (ii) Cat. $BF_3 \cdot Et_2O$, CH_2Cl_2:MeOH (3:1), 40°C, 4 days. (iii) Cat. TMSOTf, CH_2Cl_2, MS 3 Å, −30°C, 1.5 h. (iv) 3% HF in MeCN, rt, 2 h. (v) AgOTf, *sym*-collidine, CH_2Cl_2, MS 3 Å, −20°C, 12 h. (vi) (1) NaN_3, DMF, 70°C; (2) NaOMe, MeOH:toluene (5:1), rt, 19 h; (3) acetic anhydride, pyridine, rt, 20 h

of both enantiomers. Racemic diol **2** was conveniently prepared from readily available benzylidene pyruvic acid[24–26] by sodium borohydride reduction[23] of the corresponding methyl ester **17** (Scheme 3). Regioselective benzoylation of the latter then afforded alcohol **18** (71%). For butene derivatives **2** and **18** it was expected from Kazlauskas' general enzyme model[27] that enantioselective lipase-catalyzed saponification would be less efficient than for substrates **6**. Indeed, all attempts to achieve resolution by enzymatic saponification of derivatives of compounds **2** and **18** similar to the aforementioned 3-butene chloroacetates failed since cleavage of the chloroacetyl group was completely unselective (no experimental details shown here). Therefore, enzymatic esterification of **18** and methyl benzylidene lactate **19**[28] was applied using several lipases and esterases in combination with vinyl acetate in organic solvents (Table 2). Enantiomerically pure *E*-benzylidene lactic acid and derivatives thereof have been prepared previously by classical racemate resolution,[29] by enantioselective reduction of the keto group,[30–34] by enzymatic cyanohydrine synthesis[35] and, similar to our problem, by enzymatic kinetic resolution.[36] For both substrates **18** and **19** esterification with *Pseudomonas* lipases (entries 1 and 5) gave the best results in terms of E-values (cf. Table 1) as was similarly found for esterification with *Pseudomonas* sp. lipase related to *Burkholderia cepacia* (entries 2 and 6). Generally, substrate **19** was acylated more selectively than substrate **18**. For our purposes, however, products (*R*)-**19** and (*S*)-**20** had first to be reduced to diol **2** and afterwards selective protection of one hydroxy group was needed. For

preparative reactions, esterification of alcohol **18** seemed more convenient and afforded (*R*)-**18** (81% ee) in 54% yield and (*S*)-**21** (98% ee) in 45% yield on a 1 g scale.



Scheme 3. (i) $NaBH_4$, MeOH:CH_2Cl_2 (1:1), 0°C→rt, 2.5 h. (ii) BzCl, CH_2Cl_2:pyridine (2:1), −70°C, 3 h. (iii) $NaBH_4$, MeOH, −20°C, 2 h. (iv) *tert*-Butylmethylether, vinyl acetate, lipase, rt (Table 2). (v) CH_2Cl_2, cat. $BF_3 \cdot Et_2O$, −25°C, 3 h. (vi) (1) MeOH, cat. NaOMe, 1 day; (2) BzCl, CH_2Cl_2:pyridine (2:1), −70°C, 2.5 h

The assignment of the absolute configuration of **18** was performed by comparison of the specific rotations with that of an authentic sample of (*S*)-**18** prepared from known (*S*)-2,2-dimethyl-*E*-4-styryl-1,3-dioxolane.[37] From the enzymatic esterification of **19** (entry 6), the specific rotation of (*R*)-**19** was measured and compared with literature data.[31,35] Once again, compound (*S*)-**21** was converted into alcohol (*S*)-**18** by deblocking (Zemplén) and monobenzoylation of the crude diol **2** without any loss of enantiomeric purity. Enzymatic saponification of (*S*)-**21**, however, was very slow and afforded a mixture

Table 2
Enzymatic acetylation of **18** and **19** in *tert*-butylmethylether with vinyl acetate[a]

entry	enzyme	substrate	time	products alcohol (ee)	yield	ester (ee)	yield	E-value
1	*Pseudomonas sp.*[b]	**18**	8d	(***R***)-**18** (88%)	49%	(***S***)-**21** (98%)	43%	298
2	*Pseudomonas sp.*[c,d]	**18**	3d	(***R***)-**18** (86%)	49%	(***S***)-**21** (97%)	43%	183
3	*Pseudomonas sp.*[c,e]	**18**	3d	(***R***)-**18** (99%)	27%	(***S***)-**21** (16%)	57%	5.1
4	*Pseudomonas sp.*[c]	**18**	3d	(***R***)-**18** (96%)	43%	(***S***)-**21** (93%)	49%	108
5	*Pseudomonas sp.*[b]	**19**	47h	(***R***)-**19** (94%)	46%	(***S***)-**20** (99%)	46%	713
6	*Pseudomonas sp.*[c,d]	**19**	21h	(***R***)-**19** (98%)	47%	(***S***)-**20** (98%)	47%	458
7	*Pseudomonas sp.*[c,e]	**19**	72h	(***R***)-**19** (79%)	40%	(***S***)-**20** (74%)	48%	16
8	*Pseudomonas sp.*[c]	**19**	71h	(***R***)-**19** (98%)	40%	(***S***)-**20** (85%)	48%	56

[a] The acylation was monitored *via* DC and stopped when 50% of the substrate were consumed. Products were isolated by chromatography; [b] Amano PS on Celite; [c] Boehringer Mannheim GmbH, CHIRAZYM®; [d] related to *Burkholderia cepacia*; [e] cholesterol esterase.

of **18** and **2** as monitored by TLC. Next, (*S*)-**18** was shown to be suitable for direct glycosylations as exemplified by the rhamnosylation with trichloroacetimidate **22**[38], to give rhamnoside **23** in 73% yield (Scheme 3).

In summary, *Pseudomonas* lipase-catalyzed saponification is highly selective and well suitable for large scale preparations for resolutions of racemic 2-chloroacetoxy-1-thexyldimethylsiloxy-3-butene **6a** to give (*S*)-1-thexyldimethylsiloxy-3-butene-2-ol (*S*)-**5a**. The remaining (*R*)-**6a** can be conveniently converted into (*R*)-**5a** by dechloroacetylation with *Candida cylindracea* lipase. Similarly, racemic 2-acetoxy-3-butene-1-yl *p*-toluenesulfonate **6d** is selectively converted into (*R*)-**5d**. In contrast, *Pseudo-monas* lipase-catalyzed esterification in organic solvents is more suitable for racemic 3-butene-2-ol-1-yl *p*-toluenesulfonate **5d**, to give (*S*)-**5d** as well as for racemic 4-phenyl-1-benzoyloxy-*E*-3-butene-2-ol **18** which affords (*R*)-**18**. All enantiomerically pure alcohols **5a**, **5d** and **18** are easily glycosylated by glycosyl trichloroacetimidates or by halogenoses to afford the corresponding alkenyl glycosides.

3. Experimental

3.1. General

Optical rotations were measured with a Perkin–Elmer polarimeter 241 LC. Melting points were determined with a Büchi SMP-20 apparatus. The NMR data were obtained from spectra measured in $CDCl_3$ solutions for blocked compounds (with Me_4Si as an internal standard) and D_2O for deblocked compounds (with MeOH as an internal standard) at 25°C with a Bruker AC 250 F and a Bruker ARX 500 spectrometer. ^1H NMR signal assignments were made by first order analysis of the spectra. ^{13}C NMR assignments were made by mutual comparison of spectra, by DEPT spectra, by comparison with spectra of related compounds and ^1H–^{13}C correlated spectra. IR spectroscopy was performed with a Perkin–Elmer photometer 457. MS was performed with a Finnigan mass spectrometer MAT 95 in FAB-Modus. GC–MS was performed with a Hewlett–Packard 5890 GC (0.4 bar hydrogen, HP-35 capillary column 30 m) and an HP-5 mass spectrometer Finnigan MAT 95 in CI modus (methane 0.5 torr). Thin-layer chromatography (TLC) was performed on precoated plastic sheets, Polygram SIL UV_{254}, 40×80 mm (Macherey–Nagel) using appropriately adjusted mixtures of CCl_4/acetone or petroleum ether/ethyl acetate for the development. Detection was effected with UV light, where applicable, iodine and by charring with 5% H_2SO_4 in EtOH. Preparative column chromatography was performed with glass columns of different sizes packed with silica gel S, grain size 0.032–0.063 mm (Riedel de Haën). Enzymatic saponifications (Table 1) were performed analytically in aq. 0.1 M phosphate buffer pH 7.0 and monitored by titration with aq. 0.1 M NaOH solution using a Metrohm pH-stat. Products were extracted with CH_2Cl_2 and analyzed directly by GC. Enzymatic acetylations (Table 2) were performed preparatively in *tert*-butylmethylether with vinyl acetate as the acylating reagent. When 50% of the substrate was consumed (TLC), the mixtures were filtered, concentrated and the products were isolated by chromatography. The enantiomeric excess (ee) was determined by GC after deacylation (Zemplén) and acetalisation with 2,2-dimethoxypropane for **18** and **21**. For **19**, ee was determined directly by GC or after Pd-catalyzed hydrogenation of the double bond. Similarly, ee was determined for **20** after acidic removal of the acetyl group. GCs for determination of ee values: (a) Carlo Erba HRGC 5300 Mega Series with FID, Carlo Mega Series integrator, 0.4–0.6 bar hydrogen, column 20 m, Bondex-un-Et-105 (β-cyclodextrin); (b) Fisons HRGC 8560 with FID, Mega Series 2 integrator, 0.4–0.6 bar hydrogen, column 20 m, Bondex-un-a-5,6-Et-57 (β-cyclodextrin); (c) Hewlett–Packard HP 6890 Series

with FID, HP ChemStation software, 0.84–1.02 bar hydrogen, column 23 m, heptakis(2,6-di-*O*-methyl-3-*O*-pentyl)-β-cyclodextrin.

3.2. 1-Dimethylthexylsilyloxy-3-butene-2-ol **5a**

According to a literature method,[16] dimethylthexylsilyl chloride (11.7 ml, 59.62 mmol) was added at 0°C to a solution of **1**[4,10,18] (5.0 g, 56.75 mmol) and imidazole (9.67 g, 0.142 mol) in CH_2Cl_2 (100 ml). After 90 min, the mixture was diluted with CH_2Cl_2, washed with water and aq. $NaHCO_3$ solution, dried (Na_2SO_4) and concentrated. Chromatography (petroleum ether:ethyl acetate=20:1) of the residue afforded **5a** (12.38 g, 95%); ^{1}H NMR (250 MHz): δ=0.12 (s, 6H, $Si(CH_3)_2$), 0.86 (s, 6H, $Si(CH_3)_2C(CH_3)_2$), 0.89 (d, 6H, $Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$, J=6.8 Hz), 1.63 (quint, 1H, $Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$), 2.56 (d, 1H, OH, J=3.6 Hz), 3.32 (dd, 1H, 1-H_b, $J_{1b,2}$=7.6 Hz, $J_{1a,1b}$=9.9 Hz), 3.65 (dd, 1H, 1-Ha, $J_{1a,2}$=3.7 Hz), 4.16–4.17 (m, 1H, 2-H), 5.19 (dt, 1H, 4-H_{cis}, $J_{3,4cis}$=10.5 Hz, $J_{2,4cis}$=$J_{4cis,4trans}$=1.5 Hz), 5.34 (dt, 1H, 4-H_{trans}, $J_{3,4trans}$=17.3 Hz, $J_{2,4trans}$=1.6 Hz), 5.82 (ddd, 1H, 3-H); ^{13}C NMR (62.9 MHz): δ=−3.46 ($Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$), 18.5 ($Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$), 20.3 ($Si(CH_3)_2C(CH_3)_2$), 25.2 ($Si(CH_3)_2C(CH_3)_2$), 34.2 ($Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$), 66.7 (C-1), 73.0 (C-2), 116.4 (C-4), 136.7 (C-3).

3.3. 1-Benzoyloxy-3-butene-2-ol **5b**

A solution of benzoyl chloride (4.9 ml, 42.18 mmol) in pyridine (5 ml) was dropped at −35°C to a solution of **1** (3.0 g, 34.1 mmol) in pyridine (15 ml), the mixture was stirred for 17 h, poured into water and extracted with CH_2Cl_2. The combined extracts were washed with aq. 2 M HCl and $NaHCO_3$ solution, dried (Na_2SO_4) and concentrated. Chromatography (CCl_4:acetone=7:1) afforded **5b** (3.68 g, 56%); mp: 41°C (without further recrystallisation); ^{1}H NMR (250 MHz): δ=2.61 (s, 1H, OH), 4.29 (dd, 1H, 1-H_b, $J_{1b,2}$=7.4 Hz, $J_{1a,1b}$=11.4 Hz), 4.41 (dd, 1H, 1-H_a, $J_{1a,1b}$=11.4 Hz), 4.52 (bs, 1H, 2-H), 5.27 (dt, 1H, 4-H_{cis}, $J_{3,4cis}$=10.6 Hz, $J_{2,4cis}$=1.4 Hz), 5.44 (dt, 1H, 4-H_{trans}, $J_{3,4trans}$=17.3 Hz, $J_{2,4trans}$=1.4 Hz), 5.94 (ddd, 1H, 3-H, $J_{2,3}$=5.5 Hz), 8.07–7.39 (m, 5H, COC_6H_5); ^{13}C NMR (62.9 MHz): δ=68.3 (C-1), 71.1 (C-2), 117.2 (C-4), 133.2 (C-3), 166.7 (COC_6H_5); anal. calcd for $C_{11}H_{12}O_3$ (192.2): C, 68.74; H, 6.29; found: C, 68.69; H, 6.28.

3.4. 1-p-Methylbenzoyloxy-3-butene-2-ol **5c**

Compound **1** (4.00 g, 45.40 mmol) was dissolved in pyridine (100 ml) and *p*-methylbenzoyl chloride (6.6 ml, 49.91 mmol) was added at −15°C. After stirring for 15 h, the reaction mixture was hydrolyzed by addition of water (2 ml) and the solvent was removed in vacuo. The residue was redissolved in CH_2Cl_2 and washed with aq. 2 M HCl and $NaHCO_3$ solution, dried (Na_2SO_4) and concentrated. Chromatography (CCl_4:acetone=10:1) of the residue and crystallisation from petroleum ether–diethyl ether afforded **5c** (6.30 g, 67%); mp: 51–52°C; ^{1}H NMR (500 MHz): δ=2.33 (d, 1H, OH, $J_{OH,2}$=4.5 Hz), 2.41 (s, 3H, $COC_6H_4CH_3$), 4.28 (dd, 1H, 1-H_b, $J_{1b,2}$=7.2 Hz, $J_{1a,1b}$=11.4 Hz), 4.41 (dd, 1H, 1-H_a, $J_{1a,2}$=3.4 Hz), 4.53 (bs, 1H, 2-H), 5.27 (d, 1H, 4-H_{cis}, $J_{3,4cis}$=10.6 Hz), 5.44 (d, 1H, 4-H_{trans}, $J_{3,4trans}$=17.2 Hz), 5.91–5.97 (m, 1H, 3-H), 7.24, 7.94 (2d, 2×2H, $COC_6H_4CH_3$, J=8.0 Hz); ^{13}C NMR (125 MHz): δ=21.7 ($COC_6H_4CH_3$), 68.2 (C-1), 71.2 (C-2), 117.2 (C-4), 136.2 (C-3), 166.8 ($COC_6H_4CH_3$); anal. calcd for $C_{12}H_{14}O_3$ (206.2): C; 69.89; H, 6.84; found: C, 69.99; H, 6.86.

3.5. 2-Chloroacetoxy-1-dimethylthexylsilyloxy-3-butene **6a**

According to a literature method,[16] compound **5a** (18.00 g, 78.12 mmol) and chloroacetic anhydride (9.67 g, 93.70 mmol) were dissolved in pyridine (200 ml) and kept at −10°C for 1 h. The mixture was poured into ice-cold water and extracted several times with CH_2Cl_2. The combined organic layers were washed with aq. 2 M HCl and $NaHCO_3$ solution, dried (Na_2SO_4) and concentrated. Chromatography (petroleum ether:ethyl acetate=25:1) of the residue afforded **6a** (20.93 g, 73%); ^{1}H NMR (250 MHz): δ=0.09 (s, 6H, $Si(CH_3)_2$), 0.83 (s, 6H, $Si(CH_3)_2C(CH_3)_2$), 0.87 (d, 6H, $Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$, J=6.8 Hz), 1.60 (q, 1H, $Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$), 3.68–3.70 (m, 2H, 1-$H_a$, 1-$H_b$), 4.07 (s, 2H, $COCH_2Cl$), 5.24–5.32 (m, 2H, 4-H_{cis}, 4-H_{trans}), 5.36–5.43 (m, 1H, 2-H), 5.82 (ddd, 1H, 3-H, $J_{2,3}$=6.5 Hz, $J_{3,4cis}$=10.6 Hz, $J_{3,4trans}$=17.2 Hz); ^{13}C NMR (62.9 MHz): δ=−3.52 ($Si(CH_3)_2$), 18.5 ($Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$), 20.2 ($Si(CH_3)_2C(CH_3)_2$), 25.1 ($Si(CH_3)_2C(CH_3)_2$), 34.2 ($Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$), 41.0 ($CH_2Cl$), 64.2 (C-1), 77.2 (C-2), 118.8 (C-4), 132.6 (C-132.6), 166.5 ($COCH_2Cl$).

3.6. 1-Benzoyloxy-2-chloroacetoxy-3-butene **6b**

Treatment of **5b** (806 mg, 4.19 mmol) and chloroacetic anhydride (936 mg, 5.47 mmol) in pyridine (10 ml) at 0°C for 2 h as described for compound **6a** afforded **6b** (923 mg, 82%); ^{1}H NMR (250 MHz): δ=4.10 (s, 2H, CH_2Cl), 4.39 (dd, 1H, 1-H_b, $J_{1b,2}$=7.2 Hz, $J_{1a,1b}$=12.0 Hz), 4.53 (dd, 1H, 1-H_a, $J_{1a,2}$=3.5 Hz), 5.38 (dt, 1H, 4-H_{cis}, $J_{3,4cis}$=10.5 Hz, $J_{2,4}$=$J_{4cis,4trans}$=0.9 Hz), 5.49 (dt, 1H, 4-H_{trans}, $J_{3,4trans}$=17.2 Hz), 5.71–5.77 (m, 1H, 2-H), 5.90 (ddd, 1H, 3-H, $J_{2,3}$=6.3 Hz), 7.41–8.04 (m, 5H, C_6H_5); ^{13}C NMR (62.9 MHz): δ=40.9 (CH_2Cl), 64.9 (C-1), 74.1 (C-2), 120.1 (C-4), 133.3 (C-3), 166.1, 166.5 (CO); anal. calcd for $C_{13}H_{13}O_4Cl$ (268.7): C, 58.11; H, 4.88; Cl, 13.19; found: C, 58.09; H, 4.81; Cl, 13.46.

3.7. 2-Chloroacetoxy-1-p-methylbenzoyloxy-3-butene **6c**

Treatment of **5c** (500 mg, 2.42 mmol) with chloroacetic anhydride (445 mg, 2.60 mmol) in pyridine (10 ml) at 0°C for 2 h as described for compound **6a** afforded **6c** (490 mg, 71%); ^{1}H NMR (500 MHz): δ=2.41 (s, 3H, $C_6H_4CH_3$), 4.09 (s, 2H, CH_2Cl), 4.38 (dd, 1H, 1-H_b, $J_{1b,2}$=7.5 Hz, $J_{1a,1b}$=12.0 Hz), 4.50 (dd, 1H, 1-H_a, $J_{1a,2}$=3.7 Hz), 5.36–5.39 (m, 1H, 4-H_{cis}), 5.48 (dt, 1H, 4-H_{trans}, $J_{3,4trans}$=17.2 Hz, $J_{2,4trans}$=$J_{4cis,4trans}$=1.0 Hz), 5.71–5.75 (m, 1H, 2-H), 5.89 (ddd, 1H, 3-H, $J_{2,3}$=6.4 Hz, $J_{3,4cis}$=10.7 Hz), 7.24, 7.90 (2d, 2×2H, $C_6H_4CH_3$, J=8.2 Hz); ^{13}C NMR (125 MHz): δ=21.7 ($C_6H_4CH_3$), 40.9 (CH_2Cl), 64.7 (C-1), 74.1 (C-2), 120.0 (C-4), 131.3 (C-3), 166.2, 166.5 (CO); anal. calcd for $C_{14}H_{15}O_4Cl$ (282.7): C, 59.48; H, 5.35; Cl, 12.54; found: C, 59.51; H, 5.42; Cl, 12.72.

3.8. 2-Acetoxy-1-tosyloxy-3-butene **6d**

According to a literature method,[17] acetic anhydride (5 ml, 52.42 mmol) was added to a solution of **5d** (6.35g, 26.21 mmol) in pyridine (100 ml). The mixture was kept at room temperature for 4 h, poured into water and extracted several times with diethyl ether. The combined organic layers were washed with aq. 2 M HCl and $NaHCO_3$ solution, dried (Na_2SO_4) and concentrated. Chromatography (CCl_4:acetone=8:1) of the residue afforded **6d** (6.93 g, 93%); ^{1}H NMR (250 MHz): δ=2.02 (s, 3H, $COCH_3$), 2.45 (s, 3H, $C_6H_4CH_3$), 4.08 (dd, 1H, 1-H_b, $J_{1b,2}$=6.0 Hz, $J_{1a,1b}$=10.9 Hz), 4.13 (dd, 1H, 1-H_a, $J_{1a,2}$=4.1 Hz), 5.28 (dt, 1H, 4-H_{cis}, $J_{3,4cis}$=10.8, $J_{2,4cis}$=1.1 Hz), 5.32 (dt, 1H, 4-H_{trans}, $J_{3,4trans}$=17.3 Hz), 5.37–5.44 (m, 1H,

2-H), 5.72 (ddd, 1H, 3-H, $J_{2,3}$=6.3), 7.36, 7.79 (2d, 2×2H, C_6H_4, J=8.5 Hz); ^{13}C NMR (62.9 MHz): δ=20.9 (CH_3), 21.6 ($C_6H_4CH_3$), 69.8 (C-1), 71.5 (C-2), 119.8 (C-4), 132.9 (C-3), 169.7 ($COCH_3$).

3.9. Preparative kinetic resolution of **6a**

To a suspension of *Pseudomonas* lipase (1 g) in aq. 0.1 M phosphate buffer pH 7.0 (200 ml) was added **6a** (27.52 g, 89.67 mmol). The mixture was vigorously stirred and the pH was maintained at 7.0 by addition of aq. 1.0 M NaOH solution. After 4.5 h the reaction had consumed 46.487 ml of base. NaCl (40 g) was added and the solution was extracted several times with CH_2Cl_2. The combined organic layers were dried (Na_2SO_4) and concentrated. Chromatography (petroleum ether:ethyl acetate=25:1) of the residue afforded first (*S*)-**6a** (12.44 g, 45%, ee=99%), $[\alpha]_D^{20}=-2.2$ (*c*=1.2, $CHCl_3$).

Eluted next was (*R*)-**5a** (9.72 g, 47%, ee=97%); $[\alpha]_D^{20}=-3.7$ (*c*=3.4, $CHCl_3$).

3.10. (S)-1-Dimethylthexylsilyloxy-3-butene-2-ol (S)-**5a**

Compound (*S*)-**6a** (8.70 g, 28.34 mmol) was added to a vigorously stirred suspension of *Candida cylindracea* lipase (210 mg) in aq. 0.1 M phosphate buffer (pH 7.0; 150 ml) and the pH was maintained at 7.0 by addition of aq. 1.0 M NaOH solution. After 4 days, the reaction had consumed 28.173 ml of base. Workup as described for the kinetic resolution of **6a** afforded (*S*)-**5a** (7.56 g, 87%, ee=99%); $[\alpha]_D^{20}=+3.9$ (*c*=2.3, $CHCl_3$).

3.11. 2-Acetoxy-1-p-toluenesulfoxy-3-butene **6d**

According to a literature method,[13] acetic anhydride (5 ml, 52.42 mmol) was added to a solution of **5d** (6.35 g, 26.21 mmol) in pyridine (100 ml). The mixture was kept at room temperature for 4 h, poured into water and extracted several times with diethyl ether. The combined organic layers were washed with aq. 2 M HCl and $NaHCO_3$ solution, dried (Na_2SO_4) and concentrated. Chromatography (CCl_4:acetone=8:1) of the residue afforded **6d** (6.93 g, 93%); ^{1}H NMR (250 MHz): δ=2.02 (s, 3H, $COCH_3$), 2.45 (s, 3H, $SO_2C_6H_4CH_3$), 4.08 (dd, 1H, 1-H_b, $J_{1b,2}$=6.0 Hz, $J_{1a,1b}$=10.9 Hz), 4.13 (dd, 1H, 1-H_a, $J_{1a,2}$=4.1 Hz), 5.28 (dt, 1H, 4-H_{cis}, $J_{3,4cis}$=10.8 Hz, $J_{2,4cis}=J_{4cis,4trans}$=1.1 Hz), 5.32 (dt, 1H, 4-H_{trans}, $J_{3,4trans}$=17.3 Hz, $J_{2,4trans}=J_{4cis,4trans}$=1.1 Hz), 5.37–5.44 (m, 1H, 2-H), 5.72 (ddd, 1H, 3-H), 7.36, 7.79 (2d, 2×2H, $SO_2C_6H_4CH_3$, J=8.5 Hz); ^{13}C NMR (62.9 MHz): δ=20.9 (CH_3), 21.6 ($SO_2C_6H_4CH_3$), 69.8 (C-1), 71.5 (C-2), 119.8 (C-4), 132.9 (C-3), 169.7 (CO).

3.12. Preparative kinetic resolution of **6d**

Compound **6d** (6.93 g, 24.37 mmol) was treated with *Pseudomonas* lipase (150 mg) as described for the kinetic resolution of compound **6a**. After 2 h and 45 min, 12.238 ml of base had been consumed. Workup and chromatography as described above afforded first (*S*)-**6d** (3.02 g, 44%, ee=99%), $[\alpha]_D^{20}=-1.2$ (*c*=2.0, $CHCl_3$).

Eluted next was (*R*)-**5d** (2.45 g, 41%, ee=99%); mp 61–63°C (without further recrystallisation), $[\alpha]_D^{20}=+7.6$ (*c*=1.0, MeOH), Ref.[13] for (*S*)-**5d** $[\alpha]_D^{20}=-3.9$ (*c*=1.0, MeOH); ^{1}H NMR (250 MHz): δ=2.44 (s, 3H, $SO_2C_6H_4CH_3$), 2.73 (s, 1H, OH), 3.91 (dd, 1H, 1-H_b, $J_{1b,2}$=7.3 Hz, $J_{1a,1b}$=10.1 Hz), 4.05 (dd, 1H, 1-H_a, $J_{1a,2}$=3.5 Hz, $J_{1a,1b}$=10.1 Hz), 4.38 (ddd, 1H, 2-H, $J_{2,3}$=5.5 Hz), 5.22 (dt, 1H, 4-H_{cis}, $J_{3,4cis}$=10.5 Hz, $J_{2,4cis}=J_{4cis,4trans}$=1.3 Hz), 5.36 (dt, 1H, 4-H_{trans}, $J_{3,4trans}$=17.3 Hz, $J_{2,4trans}$=1.4 Hz), 5.75 (ddd, 1H,

3-H), 7.35, 7.80 (2d, 2×2H, $SO_2C_6H_4CH_3$, J=8.2 Hz); ^{13}C NMR (62.9 MHz): δ=21.6 ($SO_2C_6H_4CH_3$), 70.3 (C-2), 73.0 (C-1), 118.0 (C-4), 134.7 (C-3).

*3.13. (*R*)-2-Benzoyloxy-1-dimethylsilyloxy-3-butene (*R*)-**7***

A solution of (*R*)-**5a** (3.00 g, 13.02 mmol) in pyridine (30 ml) and benzoyl chloride (1.7 ml, 14.66 mmol) was kept at room temperature for 17 h. Workup as described for compound **5b** afforded (*R*)-**7** (4.15 g, 95%); $[\alpha]_D^{20}$=+28 (*c*=1.0, $CHCl_3$); ^{1}H NMR (250 MHz): δ=0.08, 0.09 (2×s, 6H, $Si(CH_3)_2$), 0.82 (s, 6H, $Si(CH_3)_2C(CH_3)_2$), 0.84 (d, 6H, $Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$, J=6.9 Hz), 3.80–3.82 (m, 2H, 1-H_a, 1-H_b), 5.26 (dt, 1H, 4-H_{cis}, $J_{3,4cis}$=10.6 Hz, $J_{2,4cis}$=$J_{4cis,4trans}$=1.3 Hz), 5.39 (dt, 1H, 4-H_{trans}, $J_{3,4trans}$=$J_{2,4trans}$=1.3 Hz), 5.54–5.61 (m, 1H, 2-H), 5.96 (ddd, 1H, 3-H, $J_{2,3}$=6.0 Hz), 7.26–8.09 (m, 5H, C_6H_5); ^{13}C NMR (62.9 MHz): δ=−3.5 ($Si(CH_3)_2$), 18.5 ($Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$), 20.2 ($Si(CH_3)_2C(CH_3)_2$), 25.1 ($Si(CH_3)_2C(CH_3)_2$), 34.2 ($Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$), 64.5 (C-1), 75.7 (C-2), 117.8 (C-4), 133.7 (C-3), 165.7 (CO); anal. calcd for $C_{19}H_{30}O_3$ Si (334.5): C, 68.22; H, 9.05; found: C, 68.08; H, 9.07.

*3.14. (*S*)-2-Benzoyloxy-1-dimethylthexylsilyoxy-3-butene (*S*)-**7***

Treatment of (*S*)-**5a** (3.00 g, 13.02 mmol) in pyridine (30 ml) with benzoyl chloride (1.7 ml, 14.66 mmol) as described above afforded (*S*)-**7** (4.10 g, 94%); $[\alpha]_D^{20}$=−28 (*c*=1.0, $CHCl_3$).

*3.15. (*R*)-2-Benzoyloxy-3-butene-1-ol (*R*)-**8***

A catalytic amount of $BF_3\cdot Et_2O$ (376 μl, 3.00 mmol) was added to a solution of (*R*)-**7** (4.05 g, 12.11 mmol) in a mixture of CH_2Cl_2 (60 ml) and MeOH (20 ml) and the mixture was refluxed for 4 days. After dilution with CH_2Cl_2, the solution was washed with aq. $NaHCO_3$ solution, dried (Na_2SO_4) and concentrated. Chromatograhy (CCl_4:acetone=12:1) of the residue afforded first (*R*)-**5b** (116 mg, 5%); $[\alpha]_D^{20}$=+3.1 (*c*=1.1, $CHCl_3$).

Eluted next was (*R*)-**8** (1.84 g, 79%), $[\alpha]_D^{20}$=+50 (*c*=2.1, $CHCl_3$); ^{1}H NMR (250 MHz): δ=2.11 (t, 1H, OH, J=6.2 Hz), 3.77–3.90 (m, 2H, 1-H_a, 1-H_b), 5.32 (dt, 1H, 4-H_{cis}, $J_{3,4cis}$=10.6 Hz, $J_{2,4cis}$=$J_{4cis,4trans}$=1.2 Hz), 5.44 (dt, 1H, 4-H_{trans}, $J_{3,4trans}$=17.3 Hz, $J_{2,4trans}$=17.3 Hz), 5.56–5.64 (m, 1H, 2-H), 7.41–8.10 (m, 5H, C_6H_5); ^{13}C NMR (62.9 MHz): δ=64.6 (C-1), 76.1 (C-2), 118.7 (C-4), 133.2 (C-3), 166.1 (CO); anal. calcd for $C_{11}H_{12}O_3$ (192.2): C, 68.74; H, 6.29; found: C, 68.65; H, 6.23.

*3.16. (*S*)-2-Benzoyloxy-3-butene-1-ol (*S*)-**8***

Treatment of (*S*)-**7** (3.81 g, 11.39 mmol) in a mixture of CH_2Cl_2 (60 ml) and MeOH (20 ml) with $BF_3\cdot Et_2O$ (4.00 mmol) as described above afforded first (*S*)-**5b** (161 g, 7%); $[\alpha]_D^{20}$=−3.4 (*c*=1.8, $CHCl_3$).

Eluted next was (*S*)-**8** (1.80 g, 82%); $[\alpha]_D^{20}$=−51 (*c*=1.7, $CHCl_3$); mp: 49–51°C (without further recrystallisation).

*3.17. (*R*)-1-Dimethylthexylsilyloxy-3-butene-2-yl 2,3,4,6-tetra-*O*-benzoyl-α-D-galactopyranoside **10a** and 2,3,4,6-tetra-*O*-benzoyl-β-D-galactopyranoside **10b***

A solution of TMSOTf (260 μl, 1.43 mmol) in CH_2Cl_2 (10 ml) was added at −30°C to a solution of (*R*)-**5a** (3.30 g, 14.30 mmol) and **9**[20] (12.15 g, 16.40 mmol) in CH_2Cl_2 (110 ml) containing 3 Å

molecular sieves (5 g). After stirring for 1.5 h, the mixture was neutralized with pyridine, filtered, washed with aq. 2 M HCl and $NaHCO_3$ solution, dried (Na_2SO_4) and concentrated. Chromatography (petroleum ether:ethyl acetate=8:1) of the residue afforded first **10a** (1.5 g, 13%); $[\alpha]_D^{20}=-4$ (*c*=1.2, $CHCl_3$) ^{1}H NMR (500 MHz): δ=0.07, 0.09 (s, 6H, $Si(CH_3)_2$), 0.81 (s, 6H, $Si(CH_3)_2C(CH_3)_2$), 0.84 (d, 6H, $Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$, *J*=6.9 Hz), 1.64 (quint, 1H, $Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$), 3.64 (dd, 1H, 1^1-H_b, $J_{11b,21}$=6.9 Hz, $J_{11a,11b}$=10.6 Hz), 3.70 (dd, 1H, 1^1-H_a, $J_{11a,21}$=6.4 Hz), 4.25–4.28 (m, 1H, 2^1-H), 4.74 (dd, 1H, 4^2-H, $J_{32,42}$=5.3 Hz, $J_{42,52}$=3.5 Hz), 4.76–4.77 (m, 2H, 6^2-H_a, 6^2-H_b), 5.32 (d, 1H, 4^1-H_{cis}, $J_{31,41cis}$=10.5 Hz), 5.37–5.41 (m, 2H, 1^2-H, 4^1-H_{trans}), 5.49 (s, 1H, 2^2-H), 5.63 (d, 1H, 3^2-H), 5.76 (ddd, 1H, 3^1-H, $J_{21,31}$=7.2 Hz, $J_{31,41trans}$=17.4 Hz), 6.09–6.12 (m, 1H, 5^2-H), 7.27–8.09 (m, 20H, C_6H_5); ^{13}C NMR (125 MHz): δ=−3.2, −3.1 ($Si(CH_3)_2$), 18.6, 18.7 ($Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$), 20.3, 20.4 ($Si(CH_3)_2C(CH_3)_2$), 25.3 ($Si(CH_3)_2C(CH_3)_2$), 34.2 ($Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$), 64.0 (C-$6^2$), 65.9 (C-$1^2$), 70.5 (C-$5^2$), 77.9 (C-$2^1$), 78.0 (C-$3^2$), 81.3 (C-$2^2$), 82.6 (C-$4^2$), 102.9 (C-$1^2$, $J_{C12,H12}$=176.7 Hz), 119.8 (C-4^1), 134.3 (C-3^1), 165.6, 165.9, 166.3 (CO); anal. calcd for $C_{46}H_{52}O_{11}Si$ (809.0): C, 68.30; H, 6.48; found: C, 68.55; H, 6.58.

Eluted next was **10b** (6.94 g, 60%); $[\alpha]_D^{20}=+75$ (*c*=1.0, $CHCl_3$); ^{1}H NMR: (500 MHz) δ=0.05, 0.11 (2 s, 6H, $Si(CH_3)_2$), 0.79, 0.80 (2 s, 6H, $Si(CH_3)_2C(CH_3)_2$), 0.83, 0.84 (2 d, 6H, $Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$, *J*=6.8 Hz), 1.57 (quint, 1H, $Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$), 3.61 (dd, 1H, 1^1-H_b, $J_{11b,21}$=5.5 Hz, $J_{11a,11b}$=10.7 Hz), 3.73 (dd, 1H, 1^1-H_a, $J_{11a,21}$=5.7 Hz), 4.27–4.34 (m, 1H, 2^1-H, 5^2-H), 4.42 (dd, 1H, 6^2-H_b, $J_{52,62b}$=6.7 Hz, $J_{62a,62b}$=11.3 Hz), 4.68 (dd, 1H, 6^2-H_a, $J_{52,62a}$=6.5 Hz), 4.92 (d, 1H, 1^2-H, $J_{12,22}$=8.1 Hz), 5.20–5.28 (m, 2H, 4^1-H_{cis}, 4^1-H_{trans}), 5.57 (dd, 1H, 3^2-H, $J_{22,32}$=10.4 Hz, $J_{32,42}$=3.4 Hz), 5.63 (ddd, 1H, 3^1-H, $J_{21,31}$=7.2 Hz, $J_{31,41cis}$=10.3 Hz, $J_{31,41trans}$=17.4 Hz), 5.83 (dd, 1H, 2^2-H), 5.99 (d, 1H, 4^2-H), 7.22–8.11 (m, 20H, C_6H_5); ^{13}C NMR (125 MHz): δ=−3.5, −3.2 ($Si(CH_3)_2$), 18.5 ($Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$), 20.3 ($Si(CH_3)_2C(CH_3)_2$), 25.0 ($Si(CH_3)_2C(CH_3)_2$), 34.2 ($Si(CH_3)_2C(CH_3)_2CH(CH_3)_2$), 62.0 (C-$6^2$), 65.5 (C-$1^1$), 68.1 (C-$4^2$), 69.8 (C-$2^2$), 71.1 (C-$5^2$), 72.0 (C-$3^2$), 80.0 (C-$2^1$), 98.5 (C-$1^2$), 119.2 (C-$4^1$), 134.9 (C-$3^1$), 165.1, 165.6, 166.0 (4×CO); anal. calcd for $C_{46}H_{52}O_{11}Si$ (809.0): C, 68.30; H, 6.48; found: C, 68.28; H, 6.51.

*3.18. (*R*)-1-Hydroxy-3-butene-2-yl 2,3,4,6-tetra*-O-*benzoyl-β*-D-*galactopyranoside* **11**

Aqueous 40% HF (1.5 ml) was added to a solution of **10b** (5.52 g, 6.82 mmol) in 50 ml MeCN. The mixture was kept at room temperature for 2 h, diluted with CH_2Cl_2, washed with water and aq. $NaHCO_3$ solution, dried (Na_2SO_4) and concentrated. The residue was crystallized from hexane–acetone to afford **11** (3.75 g, 82%); mp: 153–154°C; $[\alpha]_D^{20}=+110$ (*c*=1.4, $CHCl_3$); ^{1}H NMR (500 MHz): δ=2.64 (dd, 1H, OH), 3.59 (ddd, 1H, 1^1-H_b, $J_{11b,OH}$=4.4 Hz, $J_{11b,21}$=7.4 Hz, $J_{11a,11b}$=11.9 Hz), 3.64 (ddd, 1H, 1^1-H_a, $J_{11a,OH}$=9.1 Hz, $J_{11a,21}$=3.1 Hz), 4.33–4.37 (m, 2H, 2^1-H, 5^2-H), 4.50 (dd, 1H, 6^2-H_b, $J_{52,62b}$=5.9 Hz, $J_{62a,62b}$=11.5 Hz), 4.63 (dd, 1H, 6^2-H_a, $J_{52,62a}$=7.0 Hz), 4.91 (d, 1H, 1^2-H, $J_{12,22}$=8.1 Hz), 5.13 (d, 1H, 4^1-H_{cis}, $J_{31,41cis}$=10.4 Hz), 5.25 (d, 1H, 4^1-H_{trans}, $J_{31,41trans}$=17.3 Hz), 5.57–5.62 (m, 1H, 3^1-H), 5.62 (dd, 1H, 3^2-H, $J_{22,32}$=10.4 Hz, $J_{32,42}$=3.6 Hz), 5.85 (dd, 1H, 2^2-H), 6.01 (d, 1H, 4^2-H), 7.23–8.11 (m, 20H, 4×C_6H_5); ^{13}C NMR (125 MHz): δ=62.6 (C-6^2), 65.7 (C-1^1), 68.5 (C-4^2), 70.2 (C-2^2), 72.0 (C-3^2, 5^2), 83.1 (C-2^1), 100.4 (C-1^2), 119.5 (C-4^1), 134.1 (C-3^1), 165.7, 165.9, 166.0, 166.5 (4×CO); anal. calcd for $C_{38}H_{34}O_{11}$ (666.7): C, 68.46; H, 5.14; found: C, 68.38; H, 5.20.

*3.19. (*R*)-1-*p*-Toluenesulfonyloxy-3-butene-2-yl 2,3,4,6-tetra*-O-*benzoyl-β*-D-*glucopyranoside* **13**

A suspension of (*R*)-**5d** (3.00 g, 12.40 mmol), AgOTf (3.53 g, 13.60 mmol) and molecular sieves 3 Å in CH_2Cl_2 (130 ml) was stirred at room temperature for 30 min in the dark. The mixture was

cooled to −20°C and a solution of **12** (8.97 g, 13.60 mmol) and *sym*-collidine (1.32 ml, 9.92 mmol) in CH_2Cl_2 (20 ml) was added dropwise. After 12 h, the reaction mixture was neutralized with *sym*-collidine, filtered through a layer of Celite and diluted with CH_2Cl_2. The solution was washed with aq. $Na_2S_2O_3$ solution and water, followed by aq. 2 M HCl and $NaHCO_3$ solution, dried (Na_2SO_4) and concentrated. Chromatography (CCl_4:acetone=12:1) of the residue afforded **13** (8.53 g, 84%); $[\alpha]_D^{20}$=+14 (*c*=1.0, $CHCl_3$); ^{1}H NMR (250 MHz): δ=2.44 (s, 3H, $SO_2C_6H_4CH_3$), 3.97 (dd, 1H, 1^1-H_b, $J_{11b,21}$=5.3 Hz, $J_{11a,11b}$=10.4 Hz), 4.08 (dd, 1H, 1^1-H_a, $J_{11a,21}$=5.8 Hz), 4.05–4.12 (m, 1H, 5^2-H), 4.42–4.49 (m, 1H, 2^1-H), 4.45 (dd, 1H, 6^2-H_b, $J_{52,62b}$=5.5 Hz, $J_{62a,62b}$=12.1 Hz), 4.61 (dd, 1H, 6^2-H_a, $J_{52,62a}$=3.2 Hz), 4.87 (d, 1H, 1^2-H, $J_{12,22}$=7.9 Hz), 5.22–5.29 (m, 2H, 4^1-H_{cis}, 4^1-H_{trans}), 5.42 (dd, 1H, 2^2-H, $J_{22,32}$=9.7 Hz), 5.48–5.62 (m, 1H, 3^1-H), 5.71 (t, 1H, 4^2-H, $J_{32,42}$=$J_{42,52}$=9.8 Hz), 5.84 (t, 1H, 3^2-H); ^{13}C NMR (62.9 MHz): δ=21.6 ($SO_2C_6H_4CH_3$), 63.1 (C-6^2), 69.9 (C-4^2), 70.7 (C-1^1), 71.6 (C-2^2), 72.2 (C-5^2), 72.9 (C-3^2), 76.5 (C-2^1), 98.2 (C-1^2), 133.5 (C-3^1), 164.9, 165.2, 165.8, 166.1 (CO); anal. calcd for $C_{45}H_{40}O_{13}S$ (820.9): C, 65.84; H, 4.91; S, 3.91; found: C, 65.74; H, 4.90; S, 3.79.

*3.20. (*R*)-1-Azido-3-butene-2-yl 2,3,4,6-tetra*-O-*benzoyl-β-*D-*glucopyranoside* ***14***

A suspension of **13** (8.20 g, 9.99 mmol) and NaN_3 (1.61 g, 24.77 mmol) in DMF (70 ml) was heated for 1 day at 70°C. After evaporation of the solvent, the residue was dissolved in CH_2Cl_2, washed with water and aq. $NaHCO_3$ solution, dried (Na_2SO_4) and concentrated. Chromatography (CCl_4:acetone=15:1) of the residue afforded **14** (5.82 g, 84%); $[\alpha]_D^{20}$=+27 (*c*=1.0, $CHCl_3$); ^{1}H NMR (250 MHz): δ=3.21–3.35 (m, 2H, 1^1-H_a, 1^1-H_b), 4.14 (ddd, 1H, 5^2-H, $J_{42,52}$=9.7 Hz, $J_{52,62a}$=3.4 Hz, $J_{52,62b}$=5.3 Hz), 4.41–4.46 (m, 1H, 2^1-H), 4.52 (dd, 1H, 6^2-H_b, $J_{62a,62b}$=12.2 Hz), 4.67 (dd, 1H, 6^2-H_a), 4.95 (d, 1H, 1^2-H, $J_{12,22}$=7.9 Hz), 5.25–5.32 (m, 1H, 4^1-H_{cis}, 4^1-H_{trans}), 5.55–5.66 (m, 1H, 3^1-H), 5.60 (dd, 1H, 2^1-H, $J_{22,32}$=9.7 Hz), 5.69 (t, 1H, 4^2-H, $J_{32,42}$=$J_{42,52}$=9.7 Hz), 5.90 (t, 1H, 3^2-H), 7.24–8.05 (m, 20H, 4×C_6H_5); ^{13}C NMR (62.9 MHz): δ=54.2 (C-1^1), 63.0 (C-6^2), 69.7 (C-4^2), 71.8 (C-2^2), 72.2 (C-5^2), 72.9 (C-3^2), 78.3 (C-2^1), 98.1 (C-1^2), 120.4 (C-4^1), 133.7 (C-3^1), 164.9, 165.2, 165.8, 166.1 (4×CO); anal. calcd for $C_{38}H_{33}N_3O_{10}$ (691.7): C, 65.97; H, 4.81; N, 6.08; found: C, 66.12; H, 4.84; N, 5.82.

*3.21. (*R*)-1-Azido-3-butene-2-yl β-*D-*glucopyranoside* ***15***

A solution of **14** (5.38 g, 7.78 mmol) and a catalytic amount of methanolic 1 M NaOMe (500 μl, 0.50 mmol) in a mixture of MeOH (100 ml) and Toluol (20 ml) was stirred at room temperature for 19 h. After neutralization with ion-exchange resin (Dowex 50 WX8, H^+), the solution was filtered and concentrated. Chromatography ($CHCl_3$:MeOH=6:1) of the residue afforded **15** (2.08 g, 97%) as an unstable compound; $[\alpha]_D^{20}$=−31 (*c*=1.3, CH_3OH); ^{1}H NMR (500 MHz): δ=3.43–3.61 (m, 5H, 1^1-H_b, 2^2-H, 3^2-H, 4^2-H, 5^2-H), 3.65 (dd, 1H, 1^1-H_a, $J_{11a,21}$=4.1 Hz), 3.84 (dd, 1H, 6^2-H_b, $J_{52,62b}$=5.7 Hz, $J_{62a,62b}$=12.3 Hz), 4.04 (dd, 1H, 6^2-H_a, $J_{51,61a}$=1.9 Hz), 4.63 (d, 1H, 1^2-H, $J_{12,22}$=8.0 Hz), 4.63–4.67 (m, 1H, 2^1-H), 5.54 (d, 1H, 4^1-H_{cis}, $J_{31,41cis}$=10.5 Hz), 5.60 (d, 1H, 4^1-H_{trans}, $J_{31,41trans}$=17.2 Hz), 5.91 (ddd, 1H, 3^1-H, $J_{21,31}$=7.3 Hz, $J_{31,41cis}$=10.4 Hz); ^{13}C NMR (125 MHz): δ=54.4 (C-1^1), 61.1 (C-6^2), 70.0 (C-4^2), 73.4 (C-2^2), 76.1 (C-5^2), 76.2 (C-3^2), 78.2 (C-2^1), 99.5 (C-1^2), 121.1 (C-4^1), 133.9 (C-3^1); FAB-MS for $C_{10}H_{17}N_3O_6$: 276 $(M+H)^+$, 298 $(M+Na)^+$.

*3.22. (*R*)-1-Azido-3-butene-2-yl 2,3,4,6-tetra*-O-*acetyl-β-*D-*glucopyranoside* ***16***

Acetic anhydride (7.0 ml, 7.41 mmol) was added to a solution of **15** (2.03, 7.37 mmol) in pyridine (50 ml). After stirring at room temperature for 20 h, the mixture was diluted with CH_2Cl_2, washed

with water, aq. 2 M HCl and $NaHCO_3$ solution, dried (Na_2SO_4) and concentrated. Chromatography (CCl_4:acetone=8:1) of the residue followed by crystallization from petroleum ether–diethyl ether afforded **16** (2.80 g, 85%); mp: 63–64°C, $[\alpha]_D^{20}=-36$ (*c*=1.0, $CHCl_3$); ^{1}H NMR (250 MHz): δ=2.01, 2.03, 2.05, 2.10 (4 s, 12H, 4×$COCH_3$), 3.28 (dd, 1H, 1^1-Hb, $J_{11b,21}$=5.8 Hz, $J_{11a,11b}$=13.0 Hz), 3.36 (dd, 1H, 1^1-H_a, $J_{11a,21}$=4.5 Hz), 3.67 (ddd, 1H, 5^2-H, $J_{42,52}$=9.7 Hz, $J_{52,62a}$=4.5 Hz, $J_{52,62b}$=2.9 Hz), 4.17 (dd, 1H, 6^2-H_b, $J_{52,62b}$=2.9 Hz, $J_{62a,62b}$=12.3 Hz), 4.24 (dd, 1H, 6^2-Ha), 4.27–4.35 (m, 1H, 2^1-H), 4.61 (d, 1H, 1^2-H, $J_{12,22}$=7.8 Hz), 5.05 (dd, 1H, 2^2-H, $J_{22,32}$=9.3 Hz), 5.11 (t, 1H, 4^2-H, $J_{32,42}=J_{42,52}$=9.3 Hz), 5.20 (t, 1H, 3^2-H), 5.33–5.41 (m, 2H, 4^1-H_{cis}, 4^1-H_{trans}), 5.73 (ddd, 1H, 3^1-H, $J_{21,31}$=7.2 Hz, $J_{31,41cis}$=11.1 Hz, $J_{31,41trans}$=16.5 Hz); ^{13}C NMR (62.9 MHz): δ=20.6, 20.7 (4×CH_3), 54.3 (C-1^1), 61.9 (C-6^2), 68.4 (C-4^2), 71.3 (C-2^2), 71.8 (C-5^2), 72.9 (C-3^2), 78.1 (C-2^1), 97.6 (C-1^2), 120.3 (C-4^1), 133.6 (C-3^1), 169.2, 169.4, 170.3, 170.7 (4×CO); anal. calcd for $C_{18}H_{25}N_3O_{10}$ (443.4): C, 48.76; H, 5.68; N, 9.48; found: C, 48.84; H, 5.71; N, 9.43.

3.23. 4-Phenyl-E-*3-butene-1,2-diol* ***2***

Similar to a literature method,[26] methyl *E*-benzylidenepyruvate **17** (5.00 g, 26.3mmol) was dissolved in a mixture of 75 ml CH_2Cl_2 and 75 ml MeOH and the solution was cooled to 0°C. A quantity (1.50 g, 39.6 mmol) of $NaBH_4$ was added in three portions over 1 h while the solution was allowed to warm to room temperature. After 2.5 h the reaction was finished according to TLC (CH_2Cl_2:MeOH=10:1). The mixture was cooled to 0°C, a few ml acetone were added and stirring was continued for 15 min. The mixture was concentrated at <30°C and the solid residue was dissolved in water and CH_2Cl_2. A 4% solution of citric acid was added and the resulting slurry was shaken vigorously. The organic layer was separated, washed with aq. $NaHCO_3$ solution and water, dried and concentrated to afford **2** as a pale white solid (3.64 g, 84%); mp: 74–75°C; ^{1}H NMR data correspond to those given in the literature.[22,23]

3.24. 1-Benzoyloxy-4-pheny-E-*3-butene-2-ol* ***18***

A solution of benzoyl chloride (1.46 ml, 12.6 mmol) in CH_2Cl_2 (20 ml) was added at −70°C within 30 min to a solution of **2** (2.00 g, 12.2 mmol) in a mixture of 20 ml pyridine and 20 ml CH_2Cl_2. The solution was stirred for 90 min and another portion of benzoyl chloride (0.20 ml, 1.7 mmol) was added. Water was added and the mixture was diluted with CH_2Cl_2. The organic layer was separated, washed with aq. 1 M HCl and aq. $NaHCO_3$ solution, dried, concentrated and coevaporated with toluene. Recrystallisation of the residue from *n*-hexane afforded **18** (2.31 g, 71%) as colourless needles; mp: 81°C; ^{1}H NMR (250 MHz): δ=2.42 (b, 1H, OH), 4.37 (dd, 1H, 1-H_b, $J_{1a,1b}$=11.5 Hz, $J_{1b,2}$=7.3 Hz), 4.51 (dd, 1H, 1-H_a, $J_{1a,1b}$=11.4 Hz), 4.70 (m, 1H, 2-H), 6.27 (dd, 1H, 3-H, $J_{3,4}$=15.9 Hz, $J_{2,3}$=6.2 Hz), 6.77 (d, 1H, 4-H, $J_{3,4}$=15.9 Hz), 7.23–7.61 (m, 8H, arom.), 8.05–8.09 (m, 2H, *o*-H Bz); ^{13}C NMR (62.9 MHz): δ=68.5 (C-1); 71.1 (C-2); 126.6, 128.5, 128.6, 129.7 (d, Ph); 129.8, 136.3 (*ipso*-C); 127.1, 128.0 (*p*-C Ph, C-4); 132.5, 133.2 (*p*-C Bz, C-3); 166.8 (d, C=O); anal. calcd for $C_{17}H_{16}O_3$ (268.3): C, 76.10; H, 6.01; found: C, 75.88; H, 5.94.

3.25. Methyl 2-hydroxy-4-phenyl-E-*3-butenoate* ***19***

$NaBH_4$ (29 mg, 0.77 mmol) was added in two portions at −20°C to a solution of **17** (0.50 g, 2.6 mmol) in methanol (50 ml), the mixture was stirred for 30 min and stopped by addition of acetone. After 15 min, the solution was warmed to room temperature and concentrated at <30°C. The residue was dissolved in CH_2Cl_2, washed with aq. 1 M HCl and aq. $NaHCO_3$ solution, dried and concentrated. Chromatography

(*n*-hexane:ethyl acetate=5:1) of the residue afforded **19** (0.39 g, 77%) as a pale yellow oil; ^{1}H and ^{13}C NMR data correspond to those given in the literature.[28,35]

3.26. Preparative kinetic resolution of **18**

To a solution of **18** (1.00 g, 3.37 mmol) in a mixture of *t*-butylmethyl ether (30 ml) and vinylacetate (15 ml) was added 200 mg *Pseudomonas* lipase, immobilized on Celite.[39,40] The mixture was stirred at room temperature for 64 h. More of the immobilized enzyme (200 mg) was added and stirring was continued for 118 h. When TLC showed approximately 50% conversion, the solution was filtered and the filtrate was concentrated. Chromatography (*n*-hexane:ethyl acetate=5:1) of the residue afforded first (*S*)-**21** (516 mg, 45%, ee=98%); $[\alpha]_D^{20}$=+59.2 (*c*=1.22, $CHCl_3$); ^{1}H NMR (300 MHz): δ=2.12 (s, 3H, CH_3), 4.45 (dd, 1H, 1-H_b, $J_{1a,1b}$=11.7 Hz, $J_{1b,2}$=7.1 Hz), 4.55 (dd, 1H, 1-H_a, $J_{1a,1b}$=11.7 Hz, $J_{1a,2}$=3.9 Hz), 5.84 (m, 1H, 2-H), 6.21 (dd, 1H, 3-H, $J_{3,4}$=16.0 Hz, $J_{2,3}$=7.1 Hz), 6.77 (d, 1H, 4-H, $J_{3,4}$=16.0 Hz), 6.24–7,60 (m, 8H, arom.), 8.02–8.06 (m, 2H, *o*-H Bz); ^{13}C NMR (75.5 MHz): δ=21,1 (CH_3); 65.5 (C-1); 72.1 (C-2); 126.7, 128.3, 128.6, 130.0 (d, arom.); 129.8, 135.8 (*ipso*-C), 123.1 (C-4); 128.3 (*p*-Ph); 133.2, 134.6 (C-3, *p*-Bz), 166.2, 170.1 (C=O); anal. calcd for $C_{19}H_{18}O_4$ (310.4): C, 73.52; H, 5.86; found: C, 73.67; H, 6.01.

Eluted next was (*R*)-**18** (543 mg, 54%, ee=81%); $[\alpha]_D^{20}$=−3.7 (*c*=2.55, $CHCl_3$); mp: 77°C; ^{1}H NMR (300 MHz): δ=2.49 (b, 1H, OH), 4.37 (dd, 1H, 1-H_b, $J_{1a,1b}$=11.6 Hz, $J_{1b,2}$=7.4 Hz), 4.50 (dd, 1H, 1-H_a, $J_{1a,1b}$=11.5 Hz, $J_{1a,2}$=3.7 Hz), 4.71 (m, 1H, 2-H), 6.26 (dd, 1H, 3-H, $J_{3,4}$=15.9 Hz, $J_{2,3}$=6.1 Hz), 6.77 (d, 1H, 4-H, $J_{3,4}$=15.6 Hz), 7.23–7.60 (m, 8H, arom.), 8.05–8.08 (m, 2H, *o*-H Bz); ^{13}C NMR (75.5 MHz): δ=68.5 (C-1); 71.0 (C-2); 126.6, 128.4, 128.6, 129.7 (d, C-arom.); 129.8, 136.2 (*ipso*-C); 127.1, 128.0 (C-4, *p*-Ph); 132.5, 133.2 (C-3, *p*-Bz); 165.8, 166.7 (C=O).

3.27. (S)-1-Benzoyloxy-4-phenyl-E-3-butene-2-ol (S)-**18**

(*S*)-**21** (2.14 g, 6.89 mmol, ee=91%) was dissolved in a solution of a catalytic amount of NaOMe in methanol (30 ml) and the solution was stirred overnight. Ion-exchange resin (Dowex 50 WX8, H^+) was added until the solution became neutral, the mixture was filtered and concentrated. The residue was dissolved in a mixture of CH_2Cl_2 (6 ml) and pyridine (6 ml) and cooled to −70°C. Benzoyl chloride (0.82 ml, 7.1 mmol) in CH_2Cl_2 (6 ml) was added dropwise over 30 min. Workup as described for racemic **18** afforded (*S*)-**18** as colourless needles (1.46 g, 79%, ee=91%); $[\alpha]_D^{20}$=+4.1 (*c*=2.1, $CHCl_3$); mp: 81°C.

3.28. 2,3,4-Tri-O-benzoyl-α-L-rhamnopyranosyltrichloroacetimidate **22**

2,3,4-Tri-*O*-benzoyl-α-L-rhamnopyranosylbromide[41] (90.73 g, 168 mmol) was suspended in a mixture of acetone (1500 ml) and water (200 ml). NaI (2.00 g, 13.3 mmol) was added and the mixture was stirred at room temperature for 18 h. The solution was concentrated, the residue was dissolved in CH_2Cl_2, washed with water, aq. $NaHCO_3$, aq. $Na_2S_2O_3$ solution and water, and dried. Concentration then afforded 51.16 g crude 2,3,4-tri-*O*-benzoyl-L-rhamnopyranose; 20.0 g thereof was dissolved in CH_2Cl_2 (150 ml). To the cooled solution (−10°C) trichloroacetonitrile (8.3 ml, 82.2 mmol) and DBU (0.61 ml, 4.1 mmol) were added and the solution was stirred at room temperature for 12 h and concentrated. Chromatography (petroleum ether:ethyl acetate=3:1) of the residue afforded **22** (18.30 g, 45%) as a colorless foam; $[\alpha]_D^{20}$=+97.5 (*c*=1.0, $CHCl_3$); ^{1}H NMR (250 MHz) δ=1.43 (d, 3H, 6-H, $J_{5,6}$=6.2 Hz), 4.42 (dq, 1H, 5-H, $J_{4,5}$=9.7 Hz, $J_{5,6}$=6.2 Hz), 5.81 (dd, 1H, 3-H, $J_{3,4}$=9.7 Hz, $J_{2,3}$=1.3 Hz), 5.88–5.94 (m, 2H, H-2, H-4), 6.50 (d, 1H, 1-H, $J_{1,2}$=1.5 Hz), 7.23–7.66 (m, 9H, Bz), 7.81–8.13 (m, 6H, *o*-H Bz), 8.83

(s, 1H, NH); ^{13}C (62.9 MHz): δ=17.8 (C-6), 69.2 (C-5), 69.7 (d, C-2, C-3), 71.0 (C-4), 90.8 (CCl_3), 94.8 (C-1), 133.7–128.3 (arom.), 160.1 (C=NH), 165.3, 165.5, 165.7 (C=O); anal. calcd for $C_{29}H_{24}Cl_3NO_8$ (620.9): C, 56.09; H, 3.90; Cl, 17.13; N, 2.26; found: C, 56.20; H, 4.01; Cl, 16.96; N, 2.15.

*3.29. (S)-1-Benzoyloxy-4-phenyl-*E*-3-butene-2-yl 2,3,4-tri-*O*-benzoyl-α-*L*-rhamnopyranoside* ***23***

$BF_3 \cdot Et_2O$ (11 μl, 0.088 mmol) was added at −25°C to a solution of **22** (515 mg, 0.83 mmol) and (*S*)-**18** (200 mg, 0.75 mmol) in CH_2Cl_2 (15 ml). After stirring for 3 h, the solution was neutralized by addition of pyridine, diluted with CH_2Cl_2, washed with water and aq. $NaHCO_3$ solution, dried and concentrated. Chromatography (petroleum ether:ethyl acetate=8:1) of the residue afforded **23** (398 mg, 73%); $[\alpha]_D^{20}$=+82.5 (*c*=1.2, $CHCl_3$); ^{1}H NMR (250 MHz): δ=1.27 (d, 3H, 6^2-H, $J_{52,62}$=6.3 Hz), 4.29 (dq, 1H, 5^2-H, $J_{42,52}$=10.0 Hz, $J_{52,62}$=6.2 Hz), 4.47 (dd, 1H, 1^1-H_b, $J_{11a,11b}$=11.6 Hz, $J_{11b,21}$=7.8 Hz), 4.64 (dd, 1H, 1^1-H_a, $J_{11a,11b}$=11.6 Hz, $J_{11a,21}$=4.0 Hz), 4.74 (m, 1H, 2^1-H), 5.38 (d, 1H, 1^2-H, J_{12}=1.5 Hz), 5.69 (dd, 1H, 4^2-H, $J_{32,42}$=10.1 Hz, $J_{42,52}$=9.9 Hz), 5.77 (dd, 1H, 2^2-H, $J_{22,32}$=3.4 Hz, $J_{12,22}$=1.7 Hz), 5.91 (dd, 1H, 3^2-H, $J_{32,42}$=10.1 Hz, $J_{22,32}$=3.4 Hz), 6.34 (dd, 1H, 3^1-H, $J_{31,41}$=16.0 Hz, $J_{21,31}$=7.6 Hz), 6.82 (d, 1H, 4^1-H, $J_{31,41}$=16.0 Hz), 7.64–7.22 (m, 17H, arom.), 8.12–7.81 (m, 8H, *o*-H Bz); ^{13}C (62.9 MHz): δ=17.4 (C-6^2), 66.6 (C-1^1), 67.3 (C-5^2), 69.9 (C-3^2), 70.9 (C-2^2), 71.8 (C-4^2), 77.7 (C-2^1), 97.9 (C1^2), 125.1–136.0 (arom. C-3^1, C-4^1), 165.5 (d, C=O), 165.8, 166.4 (C=O); anal. calcd for $C_{44}H_{38}O_{10}$ (726.8): C, 72.71; H, 5.28; found: C, 72.46; H, 5.29.

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