Regio- and stereoselective ring opening of epoxides with sodium phenylselenide under phase transfer conditions

Reginaldo Bezerra dos Santos*[a], Valdemar Lacerda Junior[a], Paulo Roberto Zanotto[b], Timothy John Brocksom[b] and Ursula Brocksom[b]

[a]*Departamento de Química, Universidade Federal do Espírito Santo, Vitória - ES, 29075-910, Brazil*

[b]*Departamento de Química, Universidade Federal de São Carlos, C.P. 676, São Carlos - SP, 13565-905, Brazil*

The ring opening reaction of a wide range of mono-, di- and trisubstituted epoxides with the phenylselenide anion under PTC conditions provides a simple, mild and efficient method for preparation of β-hydroxy phenylselenides with high regio- and stereoselectivity in yields from 67 to 98%. The reactions are carried out in aqueous NaOH/THF using aminoiminomethanesulfinic acid (thiourea dioxide, TDO) to generate sodium phenylselenide from diphenyldiselenide.

Keywords: phenylselenide anion, opening of epoxides, thiourea dioxide

The use of arylselenide anions in various synthetic transformations is based upon the extremely high nucleophilicity of the selenium anion, coupled with facile oxidation and elimination reactions.[1-4] The phenylselenide anion has been frequently used in these applications due to the availability of diphenyldiselenide, phenylselenenyl halides and benzeneselenol. Several methods for the preparation of the phenylselenide anion have been reported.[5,6]

The conditions used in generating the phenylselenide anion involve reduction of diphenyldiselenide with $NaBH_4$ in EtOH/THF, according to the method of Sharpless.[8,9] Liotta[10] later introduced the useful variation of reducing the Se–Se bond with Na^o in refluxing THF followed by solvation in HMPA. Alternatively reduction of Ph–Se–Se–Ph can be accomplished with Na^o and ultrasound in THF,[11] resin bound borohydride,[12] $LiAlH_4$,[13] NaH in boiling THF,[14] sodium formaldehyde sulfoxylate,[15] hypophosphorous acid,[16,17] $NaBH_4/AlCl_3$ system,[18] tributylphosphine and 10% NaOH,[19] methyllithium[20] in ether or $Zn/ZrCl_4$[10] system. The deprotonation of PhSeH with NaH in dry refluxing THF has also been reported.[22]

The earliest method for generating phenylselenide anions involves the reaction of diphenyldiselenide with refluxing aqueous or ethanolic NaOH.[23] This method, where three quarters of the starting diphenyldiselenide are converted into the phenylselenide anion, is, however, unattractive for synthetic purposes owing to the drastic reaction conditions required. It is also reported[24,25] that the use of phase transfer catalysis (PTC) conditions allows this reaction to proceed under mild conditions. Some synthetic applications of aryl- and alkylchalcogenides (RS^-, RSe^- and RTe^-) obtained from the corresponding diorganodichalcogenides by reduction with aminoiminomethanesulfinic acid (thiourea dioxide, TDO) have been demonstrated.[26]

We now describe an alternative method for regio- and stereoselective nucleophilic ring opening of epoxides with the phenylselenide anion generated under phase transfer catalysis (PTC) conditions.

Results and discussion

Epoxides **1** to **7a–e** were prepared by standard methodologies of alkene epoxidation with MCPBA or enone epoxidation with H_2O_2 in a basic medium and subsequent functional group modifications. NaSePh was generated by phase transfer catalysed (Bu^n_4NBr) cleavage of Ph–Se–Se–Ph in 13% aqueous (NaOH/THF), using TDO as the reducing agent, as depicted in Scheme 1.

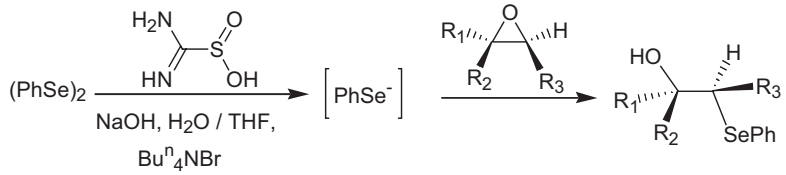
In connection with a related study on the epoxidation and subsequent nucleophilic ring opening reaction of monoterpene epoxides, we have studied the generation of the phenylselenide anion in phase transfer catalysis conditions and shown that the reaction is quite effective in the ring opening of a wide range of epoxides.

The corresponding β-hydroxy phenylselenides were obtained in good to excellent yields (Tables 1 and 2), from a variety of mono-, di- and trisubstituted epoxides of widely differing steric accessibility. All the products were isolated and characterised by spectroscopic methods (^1H NMR, ^{13}C NMR and IR) and microanalyses. Compounds **2, 4**, **9** and **11** are mixtures of epimers which were not separated.

Nucleophilic attack of phenylselenide anion at the less-substituted carbon atom was consistently observed in all the examples shown in Table 1. This afforded the corresponding β-hydroxy phenylselenides with high regio- and stereoselectivity.

The behaviour of *trans*-epoxy-carveol **7a** and the derivatives **7b**–**7e** (Scheme 2) when treated with $PhSe^-$ also was studied to evaluate the effect of the protecting group α to the epoxide (R = Piv, BOM, TBDMS and PMB) on the regio- and stereoselectivity of the reaction. The results obtained in these studies are summarised in Table 2.

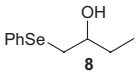
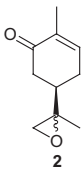
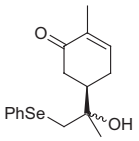
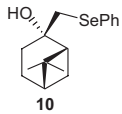
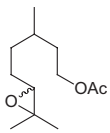
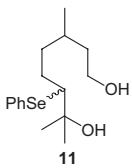
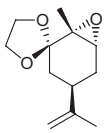
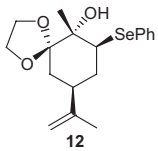
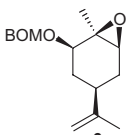
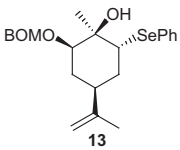
As can be seen from Table 2, the regioselectivity of the reaction is influenced by the steric bulk of the protecting group α to the epoxide. The nucleophilic attack on epoxides **7b**–**7d** seems to be controlled by steric effects, which determine the substitution at the less-branched carbon, as observed for epoxides **1**–**6**, shown in Table 1. However, without any protection of the hydroxyl group **7a**, an inversion of the regioselectivity is found. Nucleophilic



Scheme 1 Nucleophilic ring opening reaction of epoxides with $PhSe^-$ in PTC conditions.

* Correspondent. E-mail: belo.ufes@gmail.com

Table 1 Synthesis of β-hydroxy phenylselenides under phase transfer conditions

Entry	Substrate	Product	Reaction time/h	Yield/%[a]
1	 **1**	 **8**	12	98
2	 **2**	 **9**	12	75
3	 **3**	 **10**	12	72
4	 **4**	 **11**	12	71
5	 **5**	 **12**	48	94
6	 **6**	 **13**	15	90

[a] Yield of the purified product.

attack occurs preferentially at the most substituted carbon atom. This regioselectivity may be consistent with a directing effect of the hydroxyl group, through an H-bond interaction between the phenylselenide anion and the free OH.

Conclusion

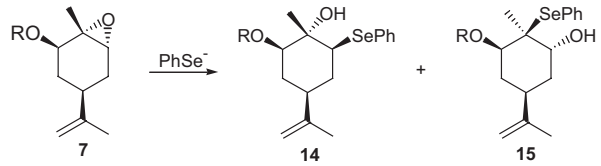
A remarkable aspect of this work is the higher efficiency and ease of generation of phenylselenide anion compared to the known methods.[8-21] The possibility of effecting the ring opening reaction of epoxides with $PhSe^-$ under mild conditions is the most important aspect of this work.

The methodology provides a convenient and efficient method for preparation of β-hydroxy phenylselenides with high regio- and stereoselectivity. These results make the procedure an attractive reaction because of the simplicity and mildness of this methodology.

Experimental

General procedure

Melting points were determined on a Micro Química model APF-301 apparatus and are uncorrected. Infrared spectra were recorded either



Scheme 2 Ring opening reaction of *trans*-epoxy-carveol derivatives with $PhSe^-$.

with a Bomem Michelson model 102 FTIR or with a Bomem Hartman & Braun MB-Series. ^1H and ^{13}C NMR spectra were recorded either on a Bruker ARX-200 (200 MHz), a Bruker ARX-400 (400 MHz) or a Varian FT-80A (80 MHz) spectrometer at a temperature of 300 K; deuteriochloroform was used as solvent and tetramethylsilane as internal standard. GC analyses were obtained on a Shimadzu GC-17A Chromatograph equipped with a DB-1 capillary column (0.25 mm i.d.x30 m), using a 1.5 ml/min H_2 carrier gas flow and a temperature program from 70°C (for 1 min) to 250°C (for 10 min) at 8°C/min. Column chromatography was performed on silica gel 60 (70-230 mesh ASTM Merck). Radial thin-layer chromatography was carried out on a Chromatotron 8924 (silica gel $60PF_{254}$ Merck). Analytical thin-layer chromatography (TLC) was performed on (10 × 5 cm) glass plates coated with silica gel 60 GF_{254} Merck: methods of detection included the use of a UV handlamp, iodine as well as vanillin acid solution. Optical rotations were taken on a Perkin-Elmer polarimeter model 241. Microanalyses were performed on a Fisons EA 1108 CHNS-0 Analyser, at the Department of Chemistry, UFSCar. Solvents were distilled prior to use.

General procedure for the β-*hydroxy phenylselenides*

13% aqueous NaOH (7 ml) and TDO (453 mg; 4.2 mmol) were added to a solution of PhSeSePh (650 mg; 2.1 mmol), Bu^n_4NBr (3.4 mg; 0.011 mmol) in THF (4 ml) under nitrogen. The two-phase system was vigorously stirred under reflux until the colour disappeared, and then the epoxide **1**–**7a**–**e** (4.2 mmol) in THF (4 ml) was added and the mixture stirred under reflux for the time indicated in Tables 1 and 2. The reaction mixture was quenched with Et_2O (20 ml), the phases were separated and the aqueous layer extracted with Et_2O (3 × 15 ml). The combined ethereal layer was washed with water (3 × 15 ml), brine (3 × 15 ml), dried with $MgSO_4$ and the solution concentrated on a rotary evaporator. The crude product was first filtered through a short column of silica-gel in hexane and then purified by silica-gel column chromatography (hexane-ethyl acetate gradients), to afford the corresponding products **8**–**15** in 67 to 98% yield as crystals or oil.

TDO is easily prepared[27] by oxidation of thiourea with cold aqueous 15% H_2O_2, with stirring for one hour, filtration and washing with ice-water, followed by crystallisation from hot ethanol.

1-phenylseleno-2-butanol (**8**): Treatment of epoxide **1** (0.303 g; 4.2 mmol) with sodium phenylselenide (4.2 mmol) gave 1-phenyl-seleno-2-butanol **8** (0.944 g; 4.12 mmol; 98%) as a pale yellow oil; IR $\nu_{max.}$ (film): 3397; 3062; 2964; 1578; 1473; 1114; 1071; 1016; 737; 691 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ: 0.91 (t, 3H, J = 7.5 Hz,); 1.47–1.61 (m, 2H); 2.77–2.92 (m, 2H); 3.10 (dd, 1H, J_1 = 12.5 and J_2 = 3.9 Hz,); 3.59 (m, 1H); 7.18–7.25 (m, 3H); 7.45–7.53 (m, 2H); ^{13}C NMR (50 MHz, $CDCl_3$) δ: 10.1; 29.4; 36.5; 71.2; 127.2; 129.1; 129.6; 132.8; Anal. Calcd for $C_{10}H_{14}OSe$: C, 52.40; H, 6.16. Found: C, 52.79; H, 6.09.

(4R,8RS)-(+)-8-hydroxy-9-phenylseleno-p-menth-6-en-2-one (**9**): Treatment of epoxide **2** (0.698 g; 4.2 mmol) with sodium phenylselenide (4.2 mmol) gave (4*R*,8*RS*)-(+)-8-hydroxy-9-phenylseleno-p-menth-6-en-2-one **9** (1.018 g; 3.15 mmol; 75%) as a pale yellow oil; IR $\nu_{max.}$ (film): 3454; 2968; 1704; 1664; 1578; 1477; 1069; 1021; 738; 692 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ: 1.22 (s, 3H); 1.75 (s, 3H); 1.90–2.60 (m, 5H); 3.14 (br. s, 2H); 6.80 (m, 1H); 7.15–7.30 (m, 3H); 7.45–7.59 (m, 2H); Anal. Calcd for $C_{16}H_{20}O_2Se$: C, 59.44; H, 6.24. Found: C, 59.62; H, 6.48.

Table 2 Regio- and stereoselectivity of the products of ring opening of *trans*-epoxy-carveol derivatives with $PhSe^-$

Entry	Substrate	Products ratio[a] (14:15)	Reaction time/h	Yield/%[b]
1	**7a**, R = H	**14a: 15a** (17: 83)	2	70
2	**7b**, R = Piv	**14a** (100) R = H	20	75
3	**7c**, R = BOM	**14c: 15c** (88: 12)	26	82
4	**7d**, R = TBDMS	**14d: 15d** (88.5: 11.5)	48	74
5	**7e**, R = PMB	**14e: 15e** (87.5: 12.5)	48	67

[a]Ratios determined by GC; [b]yield of the purified product.

(1S,2S,5R)-(–)-6,6-dimethyl-10-phenylseleno-bicyclo [3.1.1] heptan-2-ol (**10**): Treatment of epoxide **3** (0.639 g; 4.2 mmol) with sodium phenylselenide (4.2 mmol) gave (1*S*,2*S*,5*R*)-(-)-6,6-dimethyl-10-phenylseleno-bicyclo[3.1.1]heptan-2-ol **10** (0.935 g; 3.02 mmol; 72%) as a pale yellow oil; $[\alpha]_D^{23}$ –60.7 (c 1.52, $CHCl_3$); IR $\nu_{max.}$ (film): 3465; 3061; 2920; 1578; 1475; 1024; 1003; 737; 692 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ: 0.85 (s, 3H); 1.07 (s, 3H); 1.52 (d, 1H, *J* = 10.0 Hz); 1.87–2.20 (m, 8H); 3.25 (d, 1H, *J* = 12.0 Hz); 3.32 (d, 1H, *J* = 12.0 Hz,); 7.21–7.24 (m, 3H); 7.53–7.58 (m, 2H); ^{13}C NMR (50 MHz, $CDCl_3$) δ: 23.2; 24.8; 27.1; 27.2; 30.6; 37.9; 40.7; 45.0; 51.6; 75.6; 127.0; 129.0; 133.1; 133.5; Anal. Calcd for $C_{16}H_{22}OSe$: C, 62.13; H, 7.17. Found: C, 62.35; H, 7.36.

(–)-3,7-dimethyl-6-phenylseleno-octane-1,7-diol (**11**): Treatment of epoxide **4** (0.900 g; 4.2 mmol) with sodium phenylselenide (4.2 mmol) gave (–)-3,7-dimethyl-6-phenylseleno-octane-1,7-diol **11** (0.982 g; 2.98 mmol; 71%) as a pale yellow oil; IR $\nu_{max.}$ (film): 3375; 3062; 2933; 1577; 1469; 1060; 737; 692 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ: 0.88 (d, 3H, *J* = 6.4 Hz); 1.25 (s, 3H); 1.35 (s, 3H); 1.48–1.60 (m, 4H); 1.82–2.12 (m, 2H); 2.80 (m, 1H); 3.06 (m, 1H, CH–SePh); 3.54–3.69 (m, 2H); 7.23–7.27 (m, 3H); 7.58–7.61 (m, 2H); Anal. Calcd for $C_{16}H_{26}O_2Se$: C, 58.35; H, 7.96. Found: C, 58.03; H, 8.07.

(1S,4S,6S)-(+)-2,2-ethylenedioxy-6-phenylseleno-p-menth-8-en-1-ol (**12**): Treatment of epoxide **5** (0.883 g; 4.2 mmol) with sodium phenylselenide (4.2 mmol) gave (1*S*,4*S*,6*S*)-(+)-2,2-ethylenedioxy-6-phenyl seleno-p-menth-8-en-1-ol **12** (1.449 g; 3.94 mmol; 94%) as a pale yellow oil; $[\alpha]_D^{23}$ + 71.0 (c 5.0, $CHCl_3$); ^1H NMR (80 MHz, $CDCl_3$) δ: 1.38 (s, 3H); 1.65 (s, 3H); 1.95–2.30 (m, 5H); 3.50 (dd, 1H, J_1 = 13.0 and J_2 = 5.0 Hz,); 3.80–4.10 (m, 4H); 4.67 (br. s, 2H); 7.00–7.25 (m, 3H); 7.40–7.67 (m, 2H); ^{13}C NMR (20 MHz, $CDCl_3$) δ: 19.3; 20.6; 37.1; 37.2; 42.0; 54.6; 65.6; 65.7; 76.8; 109.5; 110.7; 127.4; 128.9; 129.5; 134.6; 147.2; Anal. Calcd for $C_{18}H_{24}O_3Se$: C, 58.85; H, 6.59. Found: C, 59.05; H, 6.70.

(1R,2R,4S,6R)-(–)-2-benzyloxymethoxy-6-phenyl-seleno-p-menth-8-en-1-ol (**13**): Treatment of epoxide **6** (4.200 g; 14.57 mmol) with sodium phenylselenide (16.4 mmol) gave (1*R*,2*R*,4*S*,6*R*)-(–)-2-benzyloxy methoxy-6-phenylseleno-p-menth-8-en-1-ol **13** (5.839 g; 0.013 mol; 90%) as a white crystalline solid; m.p. 56.5–57.5°C; $[\alpha]_D^{24}$ –102.9 (c 2.0, $CHCl_3$); IR $\nu_{max.}$ (KBr): 3466, 3069, 3030, 1647, 1457, 1159 cm^{-1}; ^1H NMR (80 MHz, $CDCl_3$) δ: 1.52 (s, 3H); 1.70 (s, 3H); 1.80–2.40 (m, 5H); 3.58–3.70 (m, 1H); 3.94 (dd, 1H, J_1 = 10.0 and J_2 = 5.0 Hz); 4.60–4.90 (m, 6H); 7.15–7.36 (m, 8H); 7.40–7.65 (m, 2H); ^{13}C NMR (20 MHz, $CDCl_3$) δ: 20.7; 26.9; 32.0; 32.1; 38.9; 52.9; 69.6; 73.9; 77.9; 93.1; 109.1; 127.3; 127.6; 127.7; 128.2; 128.9; 130.1; 134.3; 137.3; 148.2; Anal. Calcd for $C_{24}H_{30}O_3Se$: C, 64.71; H, 6.79. Found: C, 64.80; H, 6.79.

(1S,2R,4S,6S)-(+)-6-phenylseleno-p-menth-8-en-1,2-diol (**14a**) *and (2R,,6R)-(+)-1-phenylseleno-p-menth-8-en-2,6-diol* (**15a**): Treatment of epoxide **7a** (0.210 g; 1.25 mmol) with sodium phenylselenide (1.4 mmol) gave (1*S*,2*R*,4*S*,6*S*)-(+)-6-phenylseleno-p-menth-8-en-1,2-diol **14a** and (2*R*,6*R*)-(+)-1-phenylseleno-p-menth-8-en-2,6-diol **15a** (0.284 g; 0.873 mmol) as a white crystalline solid.

(1S,2R,4S,6S)-(+)-6-phenylseleno-p-menth-8-en-1,2-diol (**14a**): M.p. 61–63°C; $[\alpha]_D^{22}$ + 109.96 (c 0.69, $CHCl_3$); IR $\nu_{max.}$ (KBr): 3319; 3068; 2942; 1640; 1580; 1476; 1160; 1080; 894; 728 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ: 1.26 (s, 3H); 1.70 (s, 3H); 1.30–2.20 (m, 6H); 2.45 (br. s, 1H); 2.68 (br. s, 1H); 3.17 (dd, 1H, J_1 = 13.0 and J_2 = 4.0 Hz); 3.66 (dd, 1H, J_1 = 12.0 and J_2 = 4.3 Hz); 4.72 (br. s, 2H); 7.26–7.30 (m, 3H); 7.60–7.62 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 16.7; 20.6; 34.7; 37.7; 43.2; 56.5; 75.5; 76.2; 109.5; 127.4; 129.0; 129.4; 134.2; 147.1. Anal. Calcd for $C_{16}H_{22}O_2Se$: C, 59.07; H, 6.82. Found: C, 59.06; H, 6.81.

(2R,6R)-(+)-1-phenylseleno-p-menth-8-en-2,6-diol (**15a**): M.p. 65–67°C; $[\alpha]_D^{22}$ + 16.4 (c 1.5, $CHCl_3$); IR $\nu_{max.}$ (KBr): 3405; 2927; 1646; 1450; 1057; 946; 793; 739 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ: 1.31 (s, 3H); 1.76 (s, 3H); 1.46–2.52 (m, 7H); 3.73 (m, 1H); 4.21 (br. s, 1H); 4.77 (br. s, 2H); 7.30–7.38 (m, 3H); 7.61–7.63 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 20.7; 23.3; 34.3; 37.1; 37.8; 60.2; 72.7; 75.5; 109.2; 126.2; 128.8; 128.9; 138.5; 148.2; Anal. Calcd for $C_{16}H_{22}O_2Se$: C, 59.07; H, 6.82. Found: C, 59.09; H, 6.76.

(1S,2R,4S,6S)-(+)-6-phenylseleno-p-menth-8-en-1,2-diol (**14b**): Treatment of epoxide **7b** (0.252 g; 1.0 mmol) with sodium phenylselenide (1.12 mmol) gave (1*S*,2*R*,4*S*,6*S*)-(+)-6-phenylseleno-p-menth-8-en-1,2-diol **14a** (0.244 g; 0.750 mmol; 75%).

(1S,2R,4S,6S)-(+)-2-benzyloxymethyl ether-6-phenylseleno-p-menth-8-en-1-ol (**14c**) and (1S,2R,4R,6R)-(–)-2-benzyloxymethyl ether-1-phenylseleno-p-menth-8-en-6-ol (**15c**): Treatment of epoxide **7c** (0.420 g; 1.46 mmol) with sodium phenylselenide (1.64 mmol) gave (1S,2R,4S,6S)-(+)-2-benzyloxymethyl ether-6-phenyl-seleno-p-menth-8-en-1-ol **14c** and (1S,2R,4R,6R)-(–)-2-benzyloxymethyl ether-1-phenylseleno-p-menth-8-en-6-ol **15c** (0.534 g; 1.2 mmol; 82%) as a pale yellow oil;

(1S,2R,4S,6S)-(+)-2-benzyloxymethyl ether-6-phenylseleno-p-menth-8-en-1-ol (**14c**): $[\alpha]_D^{23}$ + 59.8 (c 3.3, $CHCl_3$); IR $\nu_{max.}$ (film): 3450; 3068; 2939; 1644; 1578; 1476; 1378; 1026; 891; 741 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ: 1.30 (s, 3H); 1.67 (s, 3H); 1.40–2.20 (m, 5H); 3.22 (dd, 1H, J_1 = 13.0 and J_2 = 4.0 Hz); 3.27 (br. s, 1H); 3.57 (dd, 1H, J_1 = 12.0 and J_2 = 4.0 Hz); 4.62–4.72 (m, 4H); 4.85 (d, 1H, J = 7.0 Hz); 4.95 (d, 1H, *J* = 7.0 Hz); 7.34–7.64 (m, 8H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 17.7; 20.5; 34.6; 37.3; 43.4; 55.8; 69.6; 75.2; 83.4; 94.9; 109.5; 127.3; 127.6; 127.7; 128.2; 128.8; 129.6; 134.3; 137.4; 147.0; Anal. Calcd for $C_{24}H_{30}O_3Se$: C, 64.71; H, 6.79. Found: C, 64.51; H, 6.80.

(1S,2R,4R,6R)-(–)-2-benzyloxymethyl ether-1-phenylseleno-p-menth-8-en-6-ol (**15c**): $[\alpha]_D^{23}$ -46,6 (c 1.78, $CHCl_3$); IR $\nu_{max.}$ (film): 3458; 3068; 2942; 2865; 1644; 1452; 1026; 890; 741 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ: 1.51 (s, 3H); 1.76 (s, 3H); 1.60–2.60 (m, 5H); 3.89–3.93 (m, 2H); 4.60–4.92 (m, 6H); 7.20–7.70 (m, 10H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 20.6; 24.3; 34.2; 37.4; 56.2; 69.7; 75.0; 79.3; 93.5; 109.4; 127.6; 127.8; 128.4; 128.6; 128.6; 129.0; 137.8; 138.8; 148.5. Anal. Calcd for $C_{24}H_{30}O_3Se$: C, 64.71; H, 6.79. Found: C, 64.60; H, 6.81.

(1S,2R,4S,6S)-(+)-2-tert-butyldimethylsilyl ether-6-phenylseleno-p-menth-8-en-1-ol (**14d**): Treatment of epoxide **7d** (0.283 g; 1.0 mmol) with sodium phenylselenide (1.12 mmol) gave (1*S*,2*R*,4*S*,6*S*)-(+)-2-tert-butyldimethylsilyl oxy-6-phenylseleno-p-menth-8-en-1-ol **14d** (0.325 g; 0.740 mmol; 74%) as a white crystalline solid;

(1S,2R,4S,6S)-(+)-2-tert-butyldimethylsilyloxy-6-phenyl-seleno-p-menth-8-en-1-ol (**14d**): M.p. 73-75°C; $[\alpha]_D^{22}$ + 59.6 (c 10.7, $CHCl_3$); IR $\nu_{max.}$ (KBr): 3471; 3077; 2972; 2853; 1644; 1578; 1474; 1247; 1123; 1008; 740; 693 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ: 0.08 (s, 3H); 0.11 (s, 3H); 0.90 (s, 9H); 1.24 (s, 3H); 1.67 (s, 3H); 1.30–2.10 (m, 5H); 2.48 (br. s, 1H); 3.21 (dd, 1H, J_1 = 13.2 and J_2 = 3.8 Hz); 3.58 (dd, 1H, J_1 = 11.6 and J_2 = 4.5 Hz); 4.69 (br. s, 2H); 7.24–7.63 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: –4.5; –4.8; 17.3; 20.5; 25.7; 37.1; 37.6; 43.5; 55.2; 75.8; 77.2; 109.6; 127.3; 128.9; 129.7; 134.4; 147.3; Anal. Calcd for $C_{22}H_{36}O_2SiSe$: C, 60.11; H, 8.25. Found: C, 60.15; H, 8.33.

(1S,2R,4S,6S)-(+)-2-p-methoxybenzyloxy-6-phenylseleno-p-menth-8-en-1-ol (**14e**) and *(1S,2R,4R,6R)-(–)-2-p-methoxybenzyloxy-1-phenylseleno-p-menth-8-en-6-ol* (**15e**): Treatment of epoxide **7e** (0.288 g; 1.0 mmol) with sodium phenylselenide (1.12 mmol) gave (1S,2R,4S,6S)-(+)-2-p-methoxybenzyl ether-6-phenylseleno-p-menth-8-en-1-ol **14e** and (1S,2R,4R,6R)-(–)-2-p-methoxybenzyl ether-1-phenylseleno-p-menth-8-en-6-ol **15e** (0.298 g; 0.67 mmol; 82%) as a pale yellow oil;

(1S,2R,4S,6S)-(+)-2-p-methoxybenzyloxy-6-phenylseleno-p-menth-8-en-1-ol (**14e**): $[\alpha]_D^{23}$ + 32.5 (c 2.0, $CHCl_3$); IR $\nu_{max.}$ (film): 3517; 3070; 2948; 2836; 1513; 1373; 1170; 1099; 890; 821; 741 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ: 1.30 (s, 3H); 1.67 (s, 3H); 1.30–2.20 (m, 5H); 2,76 (s, 1H); 3.21 (dd, 1H, J_1 = 13.2 and J_2 = 4.0 Hz); 3.38 (dd, 1H, J_1 = 12.0 and J_2 = 4.0 Hz); 3.78 (s, 3H); 4.62 (s, 2H); 4.69 (br. s., 1H); 4.71 (br. s., 1H); 6.85–7.63 (m, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 17.9; 20.6; 33.6; 37.5; 43.5; 55.1; 56.2; 72.0; 76.0; 83.2; 109.7; 113.7; 127.5; 129.0; 129.1; 129.7; 130.9; 134.5; 147.3; 159.0. Anal. Calcd for $C_{24}H_{30}O_3Se$: C, 64.71; H, 6.79. Found: C, 64.37; H, 6.92.

(1S,2R,4R,6R)-(–)-2-p-methoxybenzyloxy-1-phenylseleno-p-menth-8-en-6-ol (**15e**): $[\alpha]_D^{23}$ –10.0 (c 3.6, $CHCl_3$); IR $\nu_{max.}$ (film): 3466; 3070; 2933; 2862; 1612; 1513; 1451; 1248; 1024; 820; 734 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ: 1.44 (s, 3H); 1.77 (s, 3H); 1.58–2.41 (m, 5H); 2.60 (br. s., 1H); 3.29 (dd, 1H, J_1 = 9.2 and J_2 = 3.7 Hz); 3.59 (dd, 1H, J_1 = 11.3 and J_2 = 4.2 Hz); 3.80 (s, 3H); 4.40–4.80 (m, 4H); 6.85–7.65 (m, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 20.6; 24.2; 33.2; 34.3; 37.6; 55.2; 56.4; 71.0; 75.1; 80.1; 109.4; 127.4; 128.5; 128.9; 129.1; 129.4; 130.9; 134.5; 148.7; 159.0; Anal. Calcd for $C_{24}H_{30}O_3Se$: C, 64.71; H, 6.79. Found: C, 64.73; H, 6.79.

The authors wish to thank the following agencies for financial support: FAPESP, CAPES and CNPq. The (R)-(-)-carvone used as starting material was generously given by Symrise Perfumes and Aromas Ltda.

Received 27 December 2007; accepted 14 January 2008
Paper 07/5015 *doi: 10.3184/030823408X282659*

References

1 D.L.J. Clive, *Tetrahedron*, 1978, **34**, 1049.
2 H.J. Reich, *Oxidation in organic chemistry*, W.S. Trahanovsky, (ed.), Academic Press: New York, Part C, 1978, p. 1.
3 F.A. Carey and R.J. Sundberg, *Advanced Organic Chemistry, Part A: Structure and Mechanisms,* 3rd edn, Plenum Press: New York, 1990, pp 286.
4 J. March, *Advanced organic chemistry: reactions, mechanism and structure,* 4th edn, Wiley-Interscience: New York, 1992, pp 1022.
5 C. Paulmier, *Selenium reagents and intermediates in organic synthesis*, Organic Chemistry Series, J.E. Baldwin, (ed), Pergamon: Oxford, New York, 1986, pp. 25-27.
6 D. Liotta, *Acct. Chem. Res.*, 1984, **17**, 28.
7 H.J. Reich, *Acct. Chem. Res.*, 1979, **12**, 22.
8 K.B. Sharpless and R.F. Lauer, *J. Am. Chem. Soc.*, 1973, **95**, 2696.
9 K.B. Sharpless, R.F. Lauer and A.Y. Teranishi, *J. Am. Chem. Soc.*, 1973, **95**, 6137.
10 D. Liotta, W. Markiewicz and H. Santiesteban, *Tetrahedron Lett*., 1977, 4365.
11 S.V. Ley, I.A. O'Neil and C.M.R. Low, *Tetrahedron*, 1986, **42**, 5363.
12 J.V. Weber, P. Faller, G. Kirsch and M. Schneider, *Synthesis*, 1984, 1044.
13 H. Suzuki, Yoshinaga, M. Takaoka and K.Y. Hiroi, *Synthesis*,1985, 497.
14 P. Dowd and P. Kennedy, *Synth. Commun.*, 1981, **11**, 935.
15 H.J. Reich, F. Chow and S.K. Shah, *J. Am. Chem. Soc.*, 1979, **101**, 6638.
16 W.H.H. Günther, *J. Org. Chem.*, 1966, **31**, 1202.
17 W.G. Salmond, M.A. Barta, A.M. Cain and M.C. Sobala, *Tetrahedron Lett.*, 1977, 1683.
18 H. Abe, A. Yamasaki, H. Fujii and T. Harayama, *Chem. Pharm. Bull.*, 1996, **44**, 2223.
19 M. Sakakibara, K. Katsumata, Y. Watanabe, T. Toru and Y. Ueno, *Synthesis*, 1992, 377.
20 D. Liotta, U. Sunay, H. Santiestebam and W. Markiewicz, *J. Org. Chem.*, 1981, **46**, 2605.
21 S.L. Zhang anf F.S. Tian, *J. Chem. Res. (S)*, 2001, 198.
22 A. Kamimura, H. Mitsudera, S. Asano, S. Kidera and A. Kakehi, *J. Org. Chem.*, 1999, **64**, 6353.
23 H. Rheinboldt, *Houben Weyl. Methoden der Organischen Chemie*, Vol.9, Georg Thieme Verlag: Stuttgart, 1955, p. 917.
24 J.V. Comasseto, J.T.B. Ferreira, C.A. Brandt and N. Petragnani, *J. Chem. Res. (S)*, 1982, 212.
25 J.V. Comasseto, J.T.B. Ferreira and F. Simonelli, *Synth. Commun.*, 1986, **16**, 1335.
26 J.V. Comasseto, E.S. Lang, J.T.B. Ferreira, F. Simonelli and V.R. Correia, *J. Organomet. Chem.*, 1987, **334**, 329.
27 E.B. Barnett, *J. Chem. Soc*., 1910, **97**, 63.