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# Preparation of both enantiomers of cyclopropane derivatives from the reaction of vinyl selenones with di-(−)-bornyl malonate

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ABSTRACT

The reaction of vinyl selenones with di-(−)-bornyl malonate and sodium hydride occurred with low diastereoselectivity and afforded a mixture of two diastereomeric cyclopropane derivatives in comparable yields. These, however, could be easily separated by chromatography. Removal of the bornyl group afforded highly enantiomerically enriched cyclopropanes. An example of the simple conversions of these cyclopropanes into useful cyclopropane α-amino acids is also illustrated. The syntheses of several vinyl selenides and selenones are also described.



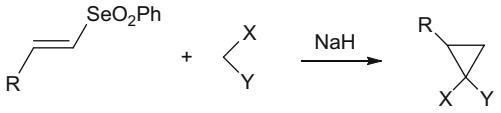
## 1. Introduction

The construction of chiral non-racemic cyclopropanes has played a prominent role in organic synthesis, because the cyclopropane unit is present in a number of useful natural and unnatural products.[1] Currently more than one hundred natural cyclopropanes are known to be therapeutically active.[2] In addition, chiral non-racemic cyclopropanes are used as synthons in the synthesis of more complex structures.[3] Numerous synthetic procedures for the preparation of optically active cyclopropanes have been developed.[4] The most generally used methods are Simmons–Smith-type reactions and the metal-catalyzed decomposition of diazo compounds in the presence of alkenes.[4] Another interesting approach is the Michael initiated ring closure (MIRC) reaction, which involves a conjugate addition to an electrophilic alkene to produce an enolate which then undergoes an intramolecular ring closure.[4a] In previous work carried out by Kuwajima et al.[5a–c] and by our group[5d] it has been reported that the treatment of vinyl selenones with methylenic compounds in basic media leads to the formation of cyclopropanes via an addition–substitution reaction (MIRC) (Scheme 1).

The selenone group activates the carbon–carbon double bond toward the addition of anionic reagents while at same time acts as a good leaving group in the following cyclization reaction.

The great leaving ability of the selenone group both in intermolecular[6a,b] and in intramolecular[6c,d] nucleophilic substitutions is well documented.

Herein we report the results of an investigation aimed at the preparation of chiral non-racemic cyclopropanes using the above-described reaction of vinyl selenones with malonates. For this purpose, we have employed di-(−)-bornyl malonate, and in some cases, the di-(−)-menthyl malonate. Owing to the structure of the starting selenones (Scheme 1), the cyclization reaction will create a new stereogenic center and thus will give rise to a mixture of two enantiomerically pure diastereoisomers.




**Scheme 1.**

## 2. Results and discussion

The aryl vinyl phenyl selenones **3a–d** necessary for the present investigation were synthesized starting from the corresponding β-bromostyrenes **1a–d**. These were converted into the corresponding aryl vinyl phenyl selenides (**2a–d**) which were then oxidized (Scheme 2, Table 1).

Bromide **1a** is commercially available. The (*E*)-bromides **1b–d** were obtained according to the procedure reported in the literature starting from cinnamic acids[7] while the (*Z*)-bromide **1d** was obtained from *anti*-2,3-dibromo-3-(4-methoxyphenyl)propanoic acid by microwave-induced debrominative decarboxylation.[8] Although various methods are reported for the preparation of aryl vinyl phenyl selenides,[9] because of their importance in synthetic organic chemistry, most of them involve the use of expensive catalysts or starting materials, which are not readily available. Herein we have employed the previously described[10] vinylic substitution of the bromides with phenyl selenide anion in dimethylformamide (Scheme 2).

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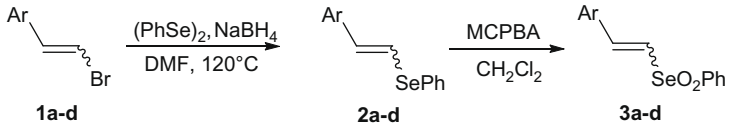


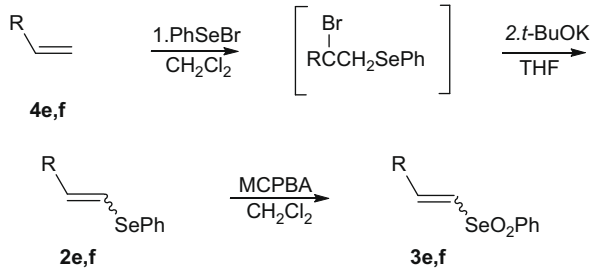

**Scheme 2.**

Interestingly, the formation of aryl vinyl phenyl selenides **2a–d** occurs with complete retention of configuration.[10] The subsequent oxidation of these selenides **2a–d** was carried out using *m*-chloroperbenzoic acid (MCPBA).[5d] The (*E*)-vinyl selenones **3a–d** were obtained in good yields, whereas (*Z*)-vinyl selenone **3d** was formed in moderate yield even with a large excess of MCPBA (Table 1).

**Table 1**

| Bromide | R | Selenide | Yield (%) | Selenone | Yield (%) |
|---|---|---|---|---|---|
| (*E*)-**1a** | Ph | (*E*)-**2a** | 94 | (*E*)-**3a** | 90 |
| (*E*)-**1b** | 4-$ClC_6H_4$ | (*E*)-**2b** | 94 | (*E*)-**3b** | 60 |
| (*E*)-**1c** | 4-$MeC_6H_4$ | (*E*)-**2c** | 72 | (*E*)-**3c** | 67 |
| (*E*)-**1d** | 4-$MeOC_6H_4$ | (*E*)-**2d** | 77 | (*E*)-**3d** | 63 |
| (*Z*)-**1d** | 4-$MeOC_6H_4$ | (*Z*)-**2d** | 76 | (*Z*)-**3d** | 40 |

The same reagent was also employed for the oxidations of the alkyl vinyl phenyl selenides **2e,f**. These were synthesized by the *one-pot* Markovnikov addition of phenylselenyl bromide to the corresponding alkenes **4e,f** followed by treatment with *t*-BuOK (Scheme 3).[9b] These alkyl selenides were obtained as a mixture of *E*- and *Z*-stereoisomers. The selenones **3e** and **3f** were therefore also obtained as a mixture of *E*- and *Z*-isomers (Table 2).




**Scheme 3.**

**Table 2**

| Alkene | R | Selenide (*E*:*Z*) | Yield (%) | Selenone (*E*:*Z*) | Yield (%) |
|---|---|---|---|---|---|
| **4e** | $PhCH_2OCH_2$ | **2e** (33:67) | 60 | **3e** (33:67) | 67 |
| **4f** | $C_6H_{13}$ | **2f** (50:50) | 84 | **3f** (50:50) | 77 |

The di-(−)-bornyl malonate **5** or the di-(−)-menthyl malonate[11] **5′** was easily prepared starting from malonyl dichloride and [(1*S*)-*endo*]-(−)-borneol or (1*R*,2*S*,5*R*)-(−)-menthol, respectively, in the presence of $Et_3N$.

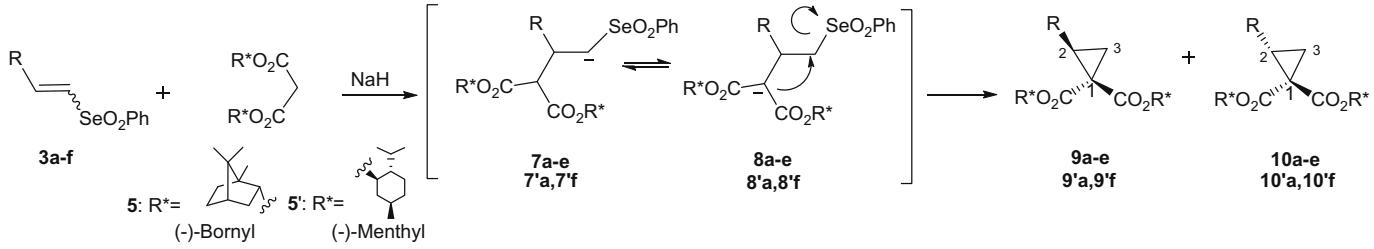
As indicated in Scheme 4, the Michael initiated ring closure (MIRC) reactions of the selenones **3a–f** with the enolate ions of the di-(−)-bornyl malonate **5** or of the di-(−)-menthyl malonate **5′** were carried out to initially give the carbanions **7a–e** or **7′a, 7′f**, which then suffered a proton transfer to **8a–e,** or **8′a, 8′f**. The intramolecular displacement of the $PhSeO_2$ group by these anions afforded a mixture of the two diastereoisomeric cyclopropane derivatives **9a–e, 10a–e** or **9′a, 10′a** or **9′f, 10′f**.

The first experiment was carried out with the styryl phenyl selenone **3a** (Table 3, entry 2) and the di-(−)-menthyl malonate **5′**. This reaction was not diastereoselective, since it afforded a 1:1 mixture (by NMR) of two diastereomeric cyclopropane derivatives **9′a** and **10′a**. In the search for a better diastereoselectivity the reaction was repeated using the di-(−)-bornyl malonate **5** (Table 3, entry 1). Unfortunately in this case, the selectivity was very low with the two cyclopropanes **9a** and **10a** being obtained in a ratio of 31:69 (by NMR). TLC analysis of the reaction mixtures showed that the two diastereoisomers gave two well-separated spots. Thus, these mixtures were submitted to medium pressure column chromatography. In this way, we could obtain both diastereoisomers in an almost pure form. The chromatographic separation was more efficient in the case of the bornyl malonate than in that of the menthyl malonate derivatives (Table 3, entries 1 and 2).

The possibility of effecting a simple preparation of both diastereoisomers of the cyclopropane derivatives and hence, after separation and removal of the chiral alcoholic moiety, both the enantiomers in an highly enriched form, induced us to carry out further experiments with other vinyl selenones using the malonate **5**.

It is interesting to note that, starting from selenones (*E*)-**3d** and (*Z*)-**3d** the same mixture of the two cyclopropane diastereoisomers **9d** and **10d** was obtained (Table 3, entries 5 and 6). In the light of these results the cyclization reactions of the alkyl vinyl phenyl selenones **3e** and **3f** were effected on the *E*- and *Z*-mixture (Table 3, entries 7 and 8).

In the case of **3e,** the chromatographic separation of the two reaction products was very poor and therefore this reaction was not further investigated. In all the other cases, the mixture of the two diastereoisomeric cyclopropanes produced was well separated by medium pressure column chromatography. The reaction of **3f** was more conveniently carried out using the di-(−)-menthyl mal-




**Scheme 4.**

**Table 3**

| Entries | Selenones **3a–f** | | Cyclopropanes **9** and **10** ($R^*$ = bornyl) or **9′** and **10′** ($R^*$ = menthyl) | | | |
|---|---|---|---|---|---|---|
| | R | *E*:*Z* | Yields[a] (%) | Diastereomeric ratio[b] (dr) | **9** or **9′** Config.,[c] dr[d] | **10** or **10′** Config.,[c] dr[d] |
| 1 | **a**: Ph | *E* | 83 | **9a:10a** = 31:69 | (*R*)-**9a**, 98:2 | (*S*)-**10a**, 98:2 |
| 2 | **a**: Ph | *E* | 77 | **9′a:10′a** = 50:50 | (*R*)-**9′a** 98:2 | (*S*)-**10′a,** 87:13 |
| 3 | **b**: 4-Cl–$C_6H_4$ | *E* | 85 | **9b:10b** = 30:70 | (*R*)-**9b**, 96:4 | (*S*)-**10b**, 96:4 |
| 4 | **c**: 4-Me–$C_6H_4$ | *E* | 68 | **9c:10c** = 50:50 | (*R*)-**9c**, 99:1 | (*S*)-**10c** 98:2 |
| 5 | **d**: 4-MeO–$C_6H_4$ | *E* | 67 | **9d:10d** = 42:58 | (*R*)-**9d,** 91:9 | (*S*)-**10d** 97:3 |
| 6 | | *Z* | 65 | **9d:10d** = 42:58 | | |
| 7 | **e**: $PhCH_2OCH_2$ | 33:67 | 73 | **9e:10e** = 50:50 | | |
| 8 | **f**: $C_6H_{13}$ | 50:50 | 86 | **9′f:10′f** = 50:50 | **9′f,** 99:1 | **10′f,** 99:1 |

[a] Determined on isolated products after column chromatography.
[b] Determined before chromatography by $^1H$ NMR of the reaction mixtures.
[c] Configuration of carbon 2 of cyclopropane.
[d] Dr of product obtained after medium pressure column chromatography. The dr was deduced from the ee of the enantiomers obtained after removal of the bornyl or menthyl groups (see Table 4).

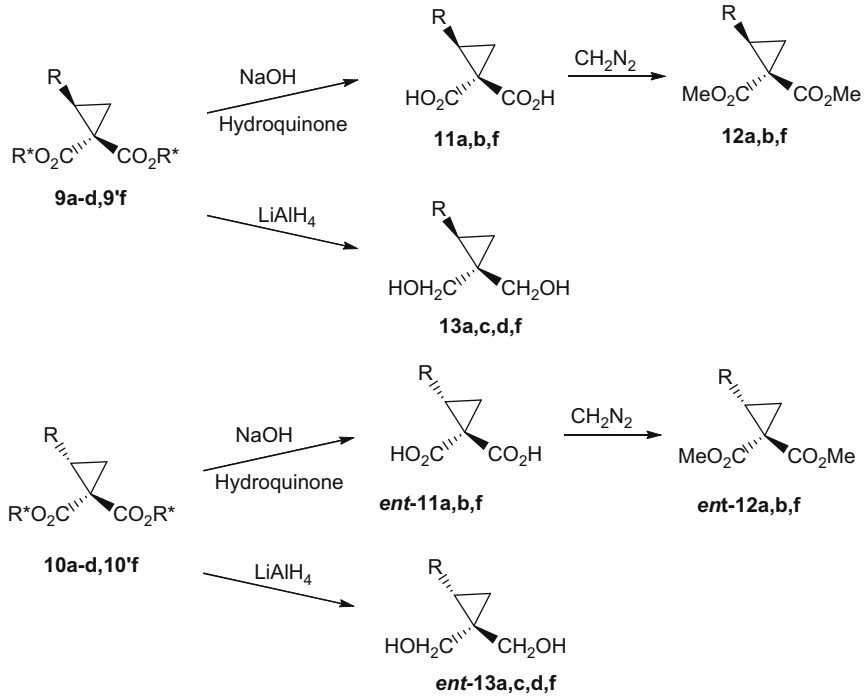
onate **5′** rather than **5**. The results of all the cyclization reactions investigated are collected in Table 3.

In order to determine the diastereomeric purity (Table 3) of the two diastereoisomers isolated by column chromatography and the absolute configurations of the newly generated stereogenic center at the 2 position of the cyclopropanes, the bornyl or menthyl groups were removed. For this purpose, compounds **9a,b, 9′f** and **10a,b, 10′f** were converted into the corresponding dimethyl esters **12a,b,f** and *ent*-**12a,b,f** (Scheme 5).

These conversions could not be effected by direct transesterification. The bornyl esters were therefore hydrolyzed with sodium hydroxide in the presence of hydroquinone to give acids **11a,b,f** and *ent*-**11a,b,f** which were then directly treated with diazomethane[12] without isolation (Scheme 5). The enantiomeric excesses of cyclopropanes **12a,b,f** and *ent*-**12a,b,f** were determined by HPLC analysis on a chiral column (Table 4). The hydrolysis of cyclopropanes **9c,d** and **10c,d** did not give clean reaction mixtures so the methyl esters were not prepared. Compounds **9c,d** and **10c,d** were reduced instead with lithium aluminum hydride to afford the corresponding diols **13c,d** and *ent*-**13c,d** (Scheme 5) whose enantiomeric excesses were determined by HPLC (Table 4). The diastereoisomers **9a**, **9′f** and **10a**, **10′f** were also converted into the corresponding diols **13a**,**f** and *ent*-**13a**,**f** (Scheme 5 and Table 4).

The absolute configurations of the newly generated stereogenic centers in compounds **12a,b** and *ent*-**12a,b** were determined by comparison of their optical properties with those reported in the literature.[13a–f] The signs of the specific rotations of **12a,b** are positive while those of *ent*-**12a,b** are negative (Table 4). These attributions are in agreement with the assumption reported in the literature according to which the specific rotation values of a series of 2-phenylcyclopropanecarboxylic acids derivatives the (*R*)-isomers have a positive sign and the (*S*)-isomers have a negative sign.[13b,f]

The absolute configurations of the 2-aryl-substituted cyclopropane diols **13c,d** and *ent*-**13c,d** are proposed to be the same as those of the methyl esters **12a,b** and *ent*-**12a,b**. In fact it seems




The absolute configuration of compounds **f** was not determined

**Scheme 5.**

**Table 4**

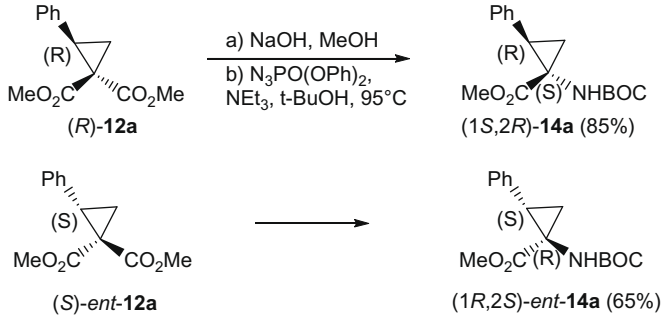
| Entries | Methyl esters **12**, *ent*-**12** and diols **13**, *ent*-**13** | | | | | |
|---|---|---|---|---|---|---|
| | Starting products | Reaction products | Yields (%) | Ee (%) | Conf. | [α] |
| 1 | **9a** | **12a** | 53 | 96 | (*R*) | +121.7 |
| 2 | **10a** | *ent*-**12a** | 51 | 96 | (*S*) | −114.3 |
| 3 | **9a** | **13a** | 92 | 96 | (*R*) | +2.2 |
| 4 | **10a** | *ent*-**13a** | 85 | 96 | (*S*) | −2.1 |
| 5 | **9b** | **12b** | 50 | 92 | (*R*) | +123.3 |
| 6 | **10b** | *ent*-**12b** | 45 | 92 | (*S*) | −117.2 |
| 7 | **9c** $PhCH_2OCH_2$ | **13c** | 88 | 98 | (*R*) | +9.9 |
| 8 | **10c** | *ent*-**13c** | 83 | 96 | (*S*) | −8.6 |
| 9 | **9d** | **13d** | 94 | 82 | (*R*) | +9.1 |
| 10 | **10d** | *ent*-**13d** | 72 | 94 | (*S*) | −9.4 |
| 11 | **9′f** | **12f** | 56 | 98 | | +53.0 |
| 12 | **10′f** | *ent*-**12f** | 70 | 98 | | −49.0 |
| 13 | **9′f** | **13f** | 83 | 98 | | +35.8 |
| 14 | **10′f** | *ent*-**13f** | 93 | 98 | | −33.8 |

reasonable to assume so since neither the hydrolysis nor the reduction reactions involve the carbon 2 of the cyclopropane ring.

The absolute configuration of 2-alkyl-substituted cyclopropanes **12f,** *ent*-**12f, 13f** and *ent*-**13f** could not be assigned.

Of particular importance is the possibility of converting chiral non-racemic cyclopropanes into cyclopropane α-amino acids (ACCs) since these compounds present various biological activities as low molecular weight inhibitors or as non-proteogenic components in peptides.[14] Several methods have been reported in the literature for their preparation,[15] yet few methods are available for a simple preparation of differently substituted cyclopropane derivatives from readily available starting materials.

Starting from our enantiomerically enriched cyclopropanes, ACCs could be easily synthesized through a few simple steps.[13c,16] Thus, cyclopropanes **12a** and *ent*-**12a** were converted into the BOC-protected amino esters **14a** and *ent*-**14a** via hydrolysis of the least encumbered ester functionality followed by a Curtius rearrangement (Scheme 6). The specific rotations of these two products are in agreement with those reported in the literature.[13c]




**Scheme 6.**

## 3. Conclusions

In conclusion the results reported in this paper illustrate a convenient approach for the synthesis of highly enantiomerically enriched cyclopropanes using vinyl selenones and chiral non-racemic methylenic compounds. It is shown that these cyclopropanes can be conveniently employed for the preparation of cyclopropane α-amino acids. The biological study of the new amino acids, as well as of their effect on the structure of peptides and proteins, is a central goal in drug discovery.[14,17]

## 4. Experimental

All new compounds were characterized by GC–MS and $^1$H and $^{13}$C NMR spectra. GC analyses and MS spectra were carried out with an HP 6890 gas chromatograph (25 m dimethyl silicone capillary column) equipped with an HP 5973 Mass Selective Detector; for the ions containing selenium, only the peaks arising from the selenium-80 isotope are given. $^1$H and $^{13}$C NMR spectra were recorded at 400 and 100.62 MHz, respectively, on a Bruker DRX 400 instrument; $CDCl_3$ was used as the solvent and TMS as the standard. FT-IR spectra were recorded with a Jasco model 410 spectrometer. HPLC analyses were performed on an HP 1100 instrument equipped with a chiral column and an UV detector. Optical rotations were measured with a Jasco DIP-1000 digital polarimeter. Elemental analyses were carried out on a Carlo Erba 1106 Elemental Analyzer.

### 4.1. Starting products

Commercial (1*R*,2*S*,5*R*)-(−)-menthol (ee 99%) and [(1*S*)-endo]-(−)-borneol (ee 99%), vinyl bromide **1a**, and alkenes **4e,f** were used without further purification. The bromides **1b**–**d** were synthesized according to the procedure described in the literature[7,8] (see Table 1). Di-(−)-menthyl malonate was prepared as described in the literature.[11]

### 4.2. Synthesis of aryl vinyl phenyl selenides

Selenide **2a** was synthesized according to the procedure reported in the literature.[10]

Sodium borohydride (6 mmol) was added to a solution of diphenyl diselenide (3 mmol) in dimethylformamide (8 mL) at 120 °C. After 45 min, a solution of the vinyl bromides **1b**–**d** was added. The progress of the reactions was monitored by TLC and by GC–MS. After 5 h the reaction mixtures were poured into aqueous $NH_4Cl$ solution and extracted with diethyl ether. The organic layers were washed with water and brine, dried over $Na_2SO_4$, filtered, and evaporated under vacuum. Reaction products were obtained in a pure form after column chromatography of the residue on silica gel using light petroleum as eluant. Reaction products and reaction yields are reported in Scheme 2 and in Table 1. The physical and spectroscopic data of compounds **2b**–**d** are reported below.

#### 4.2.1. (*E*)-2-(4-Chlorophenyl)vinyl phenyl selenide, 2b

Oil; $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): δ 7.65–7.51 (m, 2H), 7.36–7.32 (m, 3H), 7.30–7.24 (m, 4H), 7.18 (d, 1H, *J* = 15.8 Hz), 6.79 (d, 1H, *J* = 15.8 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): δ 135.4, 133.2, 133.1, 132.8 (two carbons), 129.6, 129.5 (two carbons),

128.8 (two carbons), 127.6, 127.1 (two carbons), 120.6; GC–MS (70 eV, EI): *m*/*z* (rel. int.): 294 (92), 259 (19), 214 (100), 178 (93), 165 (11), 102 (37), 75 (22), 51 (20). Anal. Calcd for $C_{14}H_{11}ClSe$: C, 57.26; H, 3.78. Found: C, 57.31; H, 3.81.

#### 4.2.2. (*E*)-2-(4-Methylphenyl)vinyl phenyl selenide, 2c

Oil, $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.57–7.52 (m, 2H), 7.35–7.29 (m, 3H), 7.25–7.22 (m, 2H), 7.15–7.09 (m, 3H), 6.90 (d, 1H, *J* = 15.7 Hz), 2.35 (s, 3H); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 137.5, 135.5, 134.1, 132.1 (two carbons), 130.4, 129.3 (two carbons), 129.2 (two carbons), 127.1, 125.9 (two carbons), 117.7, 21.1; MS (70 eV, EI): *m*/*z* (rel. int.): 274 (98), 272 (66), 259 (36), 194 (100), 179 (85), 169 (25), 115 (72), 91 (33), 77 (23), 65 (19), 51 (20). Anal. Calcd for $C_{15}H_{14}Se$: C, 65.94; H, 5.16. Found: C, 65.91; H, 5.27.

#### 4.2.3. (*E*)-2-(4-Methoxyphenyl)vinyl phenyl selenide, 2d

Oil; $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.57–7.54 (m, 2H), 7.35–7.27 (m, 5H), 7.04 (d, 1H, *J* = 15.7 Hz), 6.93–6.86 (m, 3H), 3.83 (s, 3H); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 159.2, 135.7, 131.8 (two carbons), 130.7, 129.7, 129.1 (two carbons), 127.2 (two carbons), 126.9, 115.8, 113.7 (two carbons), 55.4; GC-MS (70 eV, EI): *m*/*z* (rel. int.): 290 ($M^+$, 46), 210 (100), 195 (29), 165 (26), 89 (21), 77 (17). Anal. Calcd for $C_{15}H_{14}OSe$: C, 62.29; H, 4.88. Found: C, 62.33; H, 4.92.

#### 4.2.4. (*Z*)-2-(4-Methoxyphenyl)vinyl phenyl selenide, 2d

Mp 66–69 °C $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 764–7.55 (m, 2H), 7.42–7.27 (m, 6H), 6.97–6.93 (m, 2H), 6.67 (d, 1H, *J* = 10.3 Hz), 3.85 (s, 3H); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 158.6, 132.7 (two carbons), 131.6, 129.8, 129.7, 129.6 (two carbons), 129.1, (two carbons), 127.3, 121.0, 113.7 (two carbons), 53.4 GC–MS (70 eV, EI): *m*/*z* (rel. int.): 290 ($M^+$, 63), 210 (100), 195 (29), 165 (26), 89 (21), 77 (17). Anal. Calcd for $C_{15}H_{14}OSe$: C, 62.29; H, 4.88. Found: C, 62.35; H, 4.97.

### 4.3. Synthesis of alkyl vinyl phenyl selenides

Phenylselenyl bromide (1.2 mmol) was added to a solution of alkenes **4e, 4f** (1 mmol) in dry dichloromethane (8 mL) at room temperature and in acetonitrile (8 mL) at 80 °C, respectively. After 4 h, the reaction mixtures were directly evaporated. To the resulting residues potassium *tert*-butoxide[9b] (2 mmol) in tetrahydrofuran (8 mL) was added and the mixtures were allowed to stand for 1 h at room temperature. The reaction mixtures were poured into aqueous $NH_4Cl$ solution and extracted with diethyl ether. The organic layers were dried over $Na_2SO_4$, filtered, and evaporated under vacuum. The residues were chromatographed through a silica gel column using hexane as eluant. Reaction products and reaction yields are reported in Scheme 3 and in Table 2. The physical and spectroscopic data of compounds **2e,f** are reported below.

#### 4.3.1. {[(1*E*) and {[(1*Z*)-3-(Benzyloxy)prop-1-en-1-yl]seleno}benzene, 2e

Oil; $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.46–7.39 (m, 4H), 7.35–7.18 (m, 16H), 6.70–6.60 (m, 2H), 6.18 (dt, 1H, *J* = 5.9, 9.3 Hz, *Z*), 6.03 (dt, 1H, *J* = 5.9, 15.0 Hz, *E*), 4.50 (s, 2H, *Z*), 4.46 (s, 2H, *E*), 4.14–4.09 (m, 2H, *Z*), 4.01–3.96 (dd, 2H, *E*); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$: 138.0 (two carbons), 132.8, 132.1 (two carbons), 132.0, 131.0 (two carbons), 130.0 (two carbons), 129.3 (two carbons), 129.2 (two carbons), 128.4 (four carbons), 127.8 (two carbons), 127.7, 127.6 (two carbons), 127.4, 127.2 (two carbons), 124.5, 121.9, 72.4, 72.1, 70.9, 68.4; GC-MS (70 eV, EI): *m*/*z* (rel. int.): *first peak, (Z)*: 304 (12), 198 (67), 195 (22), 194 (18), 183 (36), 157 (26), 117 (25), 104 (27), 91 (100), 77 (27), 65 (21). *second peak, (E)*: 304 (25),198 (7), 185 (26), 183 (22), 157 (32), 115 (28), 104 (27), 91 (100), 77 (27), 65 (21).

#### 4.3.2. [(1*E*) and (1*Z*)-Oct-1-en-1-ylseleno]benzene, 2f

Oil; $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.53–7.48 (m, 4H), 7.33–7.27 (m, 6H), 6.48 (dt, 1H, *J* = 1.3, 8.9 Hz, *Z*), 6.43 (dt, 1H, *J* = 1.4, 15.1 Hz, *E*), 6.16 (dt,, 1H, *J* = 6.9, 15.1 Hz, *E*), 6.10 (dt, 1H, *J* = 7.1, 8.8 Hz, *Z*), 2,23 (dquart, 2H, *J* = 1.1, 8.0 Hz, *Z*), 2,19 (dquart, 2H, *J* = 1.1, 8.0 Hz, *E*), 1.51–1.45 (m, 4H), 1.41–1.29 (m, 12H), 0.94 (t, 6H, *J* = 6.7 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$: (mix *E*:*Z*): 140.7, 135.4, 131.7 (two carbons), 131.4, 131.3 (two carbons), 129.1 (four carbons), 126.9, 126.7, 126.6, 120.0, 115.8, 34.3, 31.7, 31.6, 31.2, 28.9 (two carbons), 28.8, 28.7, 22.6 (two carbons), 14.1 (two carbons); GC–MS (70 eV, EI): *m*/*z* (rel. int.) *first peak*: 268 (62), 195 (16), 158 (23), 117 (61), 116 (100), 91 (22), 77 (24), 55 (23); *second peak*: 268 (61), 195 (17), 158 (21), 117 (57),116 (100), 91 (21), 77 (21), 55 (19).

### 4.4. Synthesis of vinyl phenyl selenones

The oxidation of the selenides **2a**–**f** (1 mmol) was carried out in dichloromethane (4 mL) and methanol (4 mL) at room temperature using MCPBA (4 mmol) as oxidant. The progress of the reactions was monitored by TLC. The reaction mixture was poured onto 10% $Na_2CO_3$ solution, and extracted with diethyl ether. The organic layers were washed with water, dried, and evaporated. The residue was chromatographed through a deactivated silica gel column using a mixture of dichloromethane and methanol (99:1) as eluant; for the selenone **3e** the crude mixture was directly used. Reaction products and reaction yields are reported in Schemes 2 and 3 and in Tables 1 and 2. The physical and spectroscopic data of selenone **3a** were identical to those reported in the literature.[5d] The physical and spectroscopic data of compounds **3b**–**f** are reported below.

#### 4.4.1. (*E*)-2-(4-Chlorophenyl)vinyl phenyl selenone, 3b

Mp 152–153 °C; $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 8.01–7.99 (m, 2H), 7.85 (d, 1H, *J* = 15.4 Hz), 7.72–7.62 (m, 3H), 7.47–7.45 (m, 2H), 7.40–7.38 (m, 2H), 7.19 (d, 1H, *J* = 15.4 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 143.7, 141.7, 137.8, 134.1, 130.1 (two carbons), 129.8, 129.7 (two carbons), 129.4 (two carbons), 127.8, 126.6 (two carbons); FT-IR (HTAR): 936 and 881 $cm^{-1}$ ($SeO_2$). Anal. Calcd for $C_{14}H_{11}ClO_2Se$: C, 51.64; H, 3.40. Found: C, 51.84; H, 3.55.

#### 4.4.2. (*E*)-2-(4-Methylphenyl)vinyl phenyl selenone, 3c

Mp 145–148 °C; $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.94–7.91 (m, 2H), 7.78 (d, 1H, *J* = 15.4 Hz), 7.63–7.53 (m, 3H), 7.33 (d, 2H, *J* = 8.0 Hz), 7.14 (d, 2H, *J* = 8.0 Hz), 7.03 (d, 1H, *J* = 15.4 Hz), 2.31 (s, 3H); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 145.1, 142.4, 142.1, 133.9, 130.0 (two carbons), 129.7 (two carbons), 128.6, 128.5 (two carbons), 126.6 (two carbons), 126.0, 21.4; FT-IR (HTAR): 935 and 882 $cm^{-1}$ ($SeO_2$). Anal. Calcd for $C_{15}H_{14}O_2Se$: C, 59.02; H, 4.62. Found: C, 59.14; H, 4.75.

#### 4.4.3. (*E*)-2-(4-Methoxyphenyl)vinyl phenyl selenone, 3d

Mp 145–148 °C; $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 8.02–8.00 (m, 2H), 7.83 (d, 1H, *J* = 15.4 Hz), 7.71–7.61 (m, 3H), 7.48 (d, 2H, *J* = 8.8 Hz), 7.01 (d, 1H, *J* = 15.4 Hz), 6.94 (d, 2H, *J* = 8.8 Hz), 3.85 (s, 3H); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 162.3, 144.7, 142.2, 133.8, 130.5 (two carbons), 130.0 (two carbons), 126.5 (two carbons), 124.1, 123.9, 114.5 (two carbons), 55.3; FT-IR (HTAR): 930 $cm^{-1}$ and 881 $cm^{-1}$. Anal. Calcd for $C_{15}H_{14}O_3Se$: C, 56.08; H, 4.39. Found: C, 56.19; H, 4.45.

#### 4.4.4. (*Z*)-2-(4-Methoxyphenyl)vinyl phenyl selenone, 3d

Mp 136–139 °C; $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.90–7.87 (m, 2H), 7.72–7.69 (m, 2H), 7.61–7.57 (m, 1H), 7.52–7.48 (m, 2H), 7.40 (d, 1H, $J$ = 10.4 Hz), 6.88–6.83 (m, 2H), 6.62 (d, 1H, $J$ = 10.4 Hz), 3.83 (s, 3H); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 161.5, 144.8, 142.1, 133.6, 132.3 (three carbons), 129.6 (two carbons), 126.4 (two carbons), 123.8, 113.7 (two carbons), 55.1; FT-IR (HTAR): 932 and 880 cm$^{-1}$. Anal. Calcd for $C_{15}H_{14}O_3Se$: C, 56.08; H, 4.39. Found: C, 56.19; H, 4.45.

#### 4.4.5. {[(1*E*) and {[(1*Z*)-3-(Benzyloxy)prop-1-en-1-yl]selenonyl}-benzene, 3e

Oil; $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.99–7.90 (m, 4H), 7.72–7.58 (m, 6H), 7.40–7.20 (m, 11H), 7.02 (dt, 1H, $J$ = 2.2, 14.9 Hz, *E*), 6.87 (dt, 1H, $J$ = 5.4, 10.5 Hz, *Z*), 6.62 (dt, 1H, $J$ = 2.0, 10.5 Hz, *Z*), 4.72–4.67(m, 2H), 4.59 (s, 2H, *E*), 4.51 (s, 2H, *Z*), 4.32–4.29 (m, 2H); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 146.6, 145.7, 142.3, 141.1, 136.7, 136.6, 133.8 (two carbons), 133.7 (two carbons), 129.9 (two carbons), 129.8 (three carbons), 128.1 (two carbons), 128.0 (two carbons), 127.6, 127.5, 127.4 (two carbons), 127.3 (three carbons), 126.3, 125.8, 72.7 (*E*), 72.5 (*Z*), 67.5(*E*), 65.5 (*Z*); FT-IR (HTAR): 938 and 882 cm$^{-1}$ ($SeO_2$).

#### 4.4.6. [(1*E*)-Oct-1-en-1-ylselenonyl]benzene and [(1*Z*)-oct-1-en-1-ylselenonyl]benzene, 3f

Oil; $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.99–7.89 (m, 4H), 7.68–7.43 (m, 7H), 7.17 (dt, 1H, $J$ = 6.7, 15.0 Hz, *E*), 6.70–6.50 (m, 2H), 2.64 (q, 2H, $J$ = 6.7 Hz), 2.30 (q, 2H, $J$ = 7.0 Hz), 1.60–1.10 (m, 16H), 0.82 (t, 3H, $J$ = 6.7 Hz), 0.81 (t, 3H, $J$ = 6.6 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 150.6, 150.4, 133.9 (four carbons), 132.5 (two carbons), 130.1 (four carbons), 129.7 (two carbons), 126.6, 126.5, 32.0, 31.2 (two carbons), 29.4, 28.5 (two carbons), 28.2, 27.2, 22.3 (two carbons), 13.8 (two carbons). FT-IR (HTAR): 938 and 882 cm$^{-1}$ ($SeO_2$).

### 4.5. Synthesis of di-(−)-bornyl malonate 5

Malonyl dichloride (2 mmol) was slowly added to a stirred solution of $Et_3N$ (2 mmol) and (1*S*)-*endo*-(−)-borneol (4.5 mmol) in $CH_2Cl_2$ (30 mL) at −78 °C under $N_2$, and the resulting solution was warmed at room temperature and stirred for 3 h. The reaction was quenched slowly with $NH_4Cl$ and the aqueous layer was extracted with $CH_2Cl_2$. The organic phase was dried over sodium sulfate and the solvent was removed in vacuum. The residue was chromatographed through a silica gel column using a mixture of diethyl ether and light petroleum (3:97) as eluant. The physical and spectroscopic data of compound **5** are as follows: oil; $[\alpha]_D^{22} = -46.3$ (*c* 2.5, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 4.98 (ddd, 2H, $J$ = 2.1, 3.4, 9.6 Hz), 3.41 (s, 2H), 2.43–2.35 (m, 2H), 1.93 (ddd, 2H, $J$ = 5.3, 9.4, 13.2 Hz), 1.81–1.69 (m, 4H), 1.36–1.22 (m, 4H), 1.06 (dd, 2H, $J$ = 3.4, 13.7 Hz), 0.92 (s, 6H), 0.89 (s, 6H), 0.87 (s, 6H); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 166.8 (two carbons), 81.1 (two carbons), 48.8 (two carbons), 47.8 (two carbons), 44.9 (two carbons), 42.1, 46.5 (two carbons), 27.9 (two carbons), 26.9 (two carbons), 19.6 (two carbons), 18.7 (two carbons), 13.4 (two carbons). GC–MS (70 eV, EI): *m*/*z* (rel. int.): 376 (5), 154 (14), 137 (100), 121 (41), 109 (17), 95 (86), 93 (52), 81 (69), 69 (23), 67 (19), 55 (16). Anal. Calcd for $C_{23}H_{36}O_4$: C, 73.37; H, 9.64; Found: C, 73.45; H, 9.58.

### 4.6. Synthesis of cyclopropane derivatives

Sodium hydride (1.5 mmol) was added to a solution of di-(−)-bornyl malonate **5** (1 mmol) or di-(−)-menthyl malonate **5′** (1 mmol) in dry tetrahydrofuran (4 mL) at room temperature. After 30 min a solution of the selenones **3a–f** (1 mmol) in tetrahydrofuran (4 mL) was added (Table 3). The progress of the reactions (from 2 h to 8 h) was monitored by TLC. The reaction mixtures were poured into aqueous $NH_4Cl$ solution and extracted with diethyl ether. The organic layers were dried over $Na_2SO_4$, filtered, and evaporated under vacuum. The diastereoisomeric cyclopropanes **9a–e**, **10a–e** and **9′a**, **10′a**, **9′f**, **10′f** were separated by medium pressure chromatography on a silica gel column (Merk, LiChroprep® Si60, 40–63 μm) using a mixture of diethyl ether and light petroleum as eluant (from 5:95 to 10:90). The separation of the two diastereoisomers **9a** and **10a**, **9b** and **10b**, **9f** and **10f** could be easily followed by TLC. The separation of diastereoisomers **9c** and **10c**, **9d** and **10d**, which by TLC presented the same retention times, was instead monitored by $^1$H NMR. The reaction products and the reaction yields are reported in Scheme 4 and in Table 3. Physical and spectroscopic data are reported below.

#### 4.6.1. Di-(−)-bornyl-(2*R*)-2-phenylcyclopropane-1,1-dicarboxylate, 9

Mp 76–80 °C; $[\alpha]_D^{22} = +43.9$ (*c* 2.20, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.30–7.15 (m, 5H), 5.06 (ddd, 1H, $J$ = 2.0, 3.4, 9.9 Hz), 4.52 (ddd, 1H, $J$ = 2.0, 3.4, 9.9 Hz), 3.23 (t, 1H, $J$ = 8.8 Hz), 2.40 (ddt, 1H, $J$ = 3.5, 8.2, 13.5 Hz), 2.22–2.10 (m, 1H), 2.17 (dd, 1H, $J$ = 5.1, 8.8 Hz), 1,96–1.86 (m, 1H), 1.79–1.50 (m, 6H), 1.34–1.23 (m, 2H), 1.14–1.03 (m, 3H), 0.93 (s, 3H), 0.88 (s, 3H), 0.85 (s, 3H), 0.80 (dd, 1H, $J$ = 3.5, 13.8 Hz), 0.77 (s, 3H), 0.76 (s, 3H), 0.35 (s, 3H); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 170.2, 166.7, 134.8, 128.4 (two carbons), 128.2 (two carbons), 127.2, 81.3, 81.2, 49.0, 48.4, 47.8, 47.6, 44.8, 44.6, 38.0, 36.3, 35.9, 31.7, 28.0, 27.8, 27.0, 26.7, 19.6, 19.5, 18.9, 18.8, 18.6, 13.5, 12.7; GC–MS (70 eV, EI): *m*/*z* (rel. int.): 478 ($M^+$ < 1%), 342 (2), 137 (100), 95 (17), 81 (57). Anal. Calcd for $C_{31}H_{42}O_4$: C, 77.79; H, 8.84; N. Found: C, 77.85; H, 8.93.

#### 4.6.2. Di-(−)-bornyl-(2*S*)-2-phenylcyclopropane-1,1-dicarboxylate, 10a

Mp 127–130 °C; $[\alpha]_D^{22} = -113.9$ (*c* 2.8, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.32–7.22 (m, 5H), 4.99 (ddd, 1H, $J$ = 3.5, 5.3, 9.9 Hz), 4.53 (ddd, 1H, $J$ = 3.5, 5.3, 9.9 Hz), 3.20 (t, 1H, $J$ = 8.4 Hz), 2.40 (ddt, 1H, $J$ = 3.5, 8.0, 13.7 Hz), 2.14 (dd, 1H, $J$ = 5.2, 8.4 Hz), 2.02–1.89 (m, 2H), 1.77–1.74 (m, 1H), 1.73–1.66 (m, 3H), 1.59–1.51 (m, 2H), 1.33–1.23 (m, 2H), 1.18–1.12 (m, 1H), 1.02 (dd, 1H, $J$ = 3.4, 13.8 Hz), 0.92 (s, 3H), 0.88 (s, 6H), 0.84–0.79 (m, 1H), 0.78 (s, 3H), 0.72 (s, 3H), 0.77 (s, 3H), 0.08 (dd, 1H, $J$ = 3.4, 13.9 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 169.9, 166.8, 134.7, 128.4 (two carbons), 128.2 (two carbons), 127.2, 81.6, 81.4, 48.8, 48.3, 47.9, 47.4, 44.7, 44.4, 38.2, 36.7, 35.8, 31.5, 27.9, 27.4, 27.0, 26.9, 19.6, 19.5, 18.7, 18.6, 18.4, 13.6, 13.5; GC–MS (70 eV, EI): *m*/*z* (rel. int.): 478 ($M^+$ <1%), 342 (1), 171 (6), 137 (100), 81 (53), 69 (10). Anal. Calcd for $C_{31}H_{42}O_4$: C, 77.79; H, 8.84; N. Found: C, 77.68; H, 8.71.

#### 4.6.3. Di-(−)-menthyl-(2*R*)-2-phenylcyclopropane-1,1-dicarboxylate, 9′a

Mp 66–70 °C; $[\alpha]_D^{19} = +34.6$ (*c* 1.69, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.28–7.19 (m, 5H), 4.75 (dt, 1H, $J$ = 4.4, 10.9 Hz), 4.44 (dt, 1H, $J$ = 4.4, 10.9 Hz), 3.20 (t, 1H, $J$ = 8.6 Hz), 2.15 (dd, 1H, $J$ = 5.1, 8.6 Hz), 2.15–2.10 (m, 1H), 1.90 (dsept, 1H, $J$ = 4.2, 6.8 Hz), 1.87–1.78 (m, 1H), 1.71–1.66 (m, 2H), 1.61 (dd, 1H, $J$ = 5.1, 8.6 Hz), 1.63–1.45 (m, 4H), 1.45–1.30 (m, 3H), 1.18–0.96 (m, 3H), 0.94–0.87 (m, 2H), 0.93 (d, 3H, $J$ = 6.5 Hz), 0.90 (d, 3H, $J$ = 7.0 Hz), 0.85 (d, 3H, $J$ = 6.58 Hz), 0.79–0.75 (m, 1H), 0.78 (d, 3H, $J$ = 6.8 Hz), 0.63 (d, 3H, $J$ = 6.8 Hz), 0.31 (d, 3H, $J$ = 6.8 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 169.7, 166.2, 134.7, 128.3 (two carbons), 128.2 (two carbons), 127.2, 75.8, 75.2, 47.2, 46.5, 40.8, 40.5, 38.5, 34.3, 34.1, 31.7, 31.4, 31.2, 26.3, 24.9, 23.5, 22.8, 22.0 (two carbons), 20.8, 20.7, 18.5, 16.4, 15.7; GC–MS (70 eV, EI): *m*/*z* (rel. int.): 482 ($M^+$< 1%), 344 (7), 207 (76), 206

(98), 189 (33), 171 (34), 138 (60), 83 (100), 69 (40), 55 (54). Anal. Calcd for $C_{31}H_{46}O_4$: C, 77.14; H, 9.61. Found: C, 77.23; H, 9.76.

#### 4.6.4. Di-(−)-menthyl-(2*S*)-2-phenylcyclopropane-1,1-dicarboxylate, 10′a

Mp 108–111 °C; $[\alpha]_D^{18} = -86.0$ (*c* 0.84, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.28–7.19 (m, 5H), 4.85 (dt, 1H, *J* = 4.4, 10.8 Hz), 4.45 (dt, 1H, *J* = 4.4, 10.9 Hz), 3.17 (t, 1H, *J* = 8.5 Hz), 2.17 (dd, 1H, *J* = 5.0, 8.0 Hz), 2.05–1.86 (m, 3H), 1.72 (dd, 1H, *J* = 5.0, 8.0 Hz), 1.72–1.64 (m, 2H), 1.65–1.09 (m, 13H), 0.93 (d, 3H, *J* = 7.0 Hz), 0.92 (d, 3H, *J* = 6.5 Hz), 0.86 (d, 3H, *J* = 7.0 Hz), 0.83 (d, 3H, *J* = 6.9 Hz), 0.71 (d, 3H, *J* = 6.5 Hz), 0.66 (d, 3H, *J* = 6.9 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 169.7, 166.3, 134.7, 128.8 (two carbons), 128.1 (two carbons), 127.3, 75.5, 75.3, 47.2, 46.8, 40.9, 39.8, 37.9, 34.2, 34.0, 32.9, 31.5, 31.1, 25.9, 25.1, 23.1, 22.5, 22.0, 21.8, 21.2, 21.0, 18.5, 16.1, 15.5; GC–MS (70 eV, EI): *m*/*z* (rel. int.): 482 ($M^+$<1%), 344 (6), 207 (72), 206 (91), 189 (29), 171 (30), 138 (57), 83 (100), 69 (41), 55 (54). Anal. Calcd for $C_{31}H_{46}O_4$: C, 77.14; H, 9.61;. Found: C, 77.29; H, 9.72.

#### 4.6.5. Di-(−)-bornyl-(2*R*)-2-(4-chlorophenyl) cyclopropane-1,1-dicarboxylate, 9b

Oil; $[\alpha]_D^{25} = +55.2$ (*c* 1.30, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.24 (d, 2H, *J* = 8.4 Hz), 7.15 (d, 2H, *J* = 8.4 Hz), 5.06 (ddd, 1H, *J* = 2.0, 3.5, 9.9 Hz), 4.54 (ddd, 1H, *J* = 2.0, 3.5, 9.9 Hz), 3.18 (t, 1H, *J* = 8.5 Hz), 2.38 (ddt, 1H, *J* = 3.5, 9.9, 13.6 Hz), 2.19 (ddt, 1H, *J* = 4.0, 9.8, 13.6 Hz), 2.12 (dd, 1H, *J* = 5.1, 8.5 Hz), 1.91–1.80 (m, 1H), 1.75–1.50 (m, 5H), 1.40–1.20 (m, 3H), 1.15–1.03 (m, 3H), 0.92 (s, 3H), 0.88 (s, 3H), 0.85 (s, 3H), 0.84 (dd, 1H, *J* = 3.5, 13.6 Hz), 0,78 (s, 6H), 0.36 (s, 3H); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 169.9, 166.6, 133.4, 133.2, 129.8 (two carbons), 128.4 (two carbons), 81.5, 81.4, 49.0, 48.5, 47.9, 47.7, 44.8, 44.6, 38.1, 36.2, 36.1, 31.0, 28.0, 27.9, 27.1, 26.8, 19.7, 19.6, 18.9, 18.8, 18.7, 13.5, 12.7; GC–MS (70 eV, EI): *m*/*z* (rel. int.): 512 ($M^+$<1%), 137 (100), 95 (17), 81 (60), 69 (11), 55 (5). Anal. Calcd for $C_{31}H_{41}ClO_4$: C, 72.56; H, 8.05. Found: C, 73.01; H, 8.14.

#### 4.6.6. Di-(−)-bornyl-(2*S*)-2-(4-chlorophenyl) cyclopropane-1,1-dicarboxylate, 10b

Oil; $[\alpha]_D^{24} = -84.7$ (*c* 1.26, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.26 (d, 2H, *J* = 8.5 Hz) 7.19 (d, 2H, *J* = 8.5 Hz), 5,01 (ddd, 1H, *J* = 2.4, 3.9, 9.8 Hz), 4.57 (ddd, 1H, *J* = 2.4, 3.9, 9.8 Hz), 3.16 (t, 1H, *J* = 8.6 Hz), 2.40–2.37 (m, 1H), 2.10 (dd, 1H, *J* = 5.2, 7.7 Hz), 2.09–2.01 (m, 1H), 1.94–1.90 (m, 1H), 1.77–1.61 (m, 5H), 1.51 (t, 1H, *J* = 4.4 Hz), 1.34–1.16 (m, 3H), 1.02 (dd, 1H, *J* = 3.4, 13.8 Hz), 0.93 (s, 3H), 0.92–0.89 (m, 1H), 0.89 (s, 6H), 0.80 (s, 6H), 0.73 (s, 3H), 0,18 (dd, 1H, *J* = 3.5, 13.9 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 169.8, 166.7, 133.4, 133.1, 129.8 (two carbons), 128.4 (two carbons), 81.8, 81.6, 48.8, 48.4, 47.9, 47.5, 44.7, 44.4, 38.2, 36.7, 36.1, 31.0, 27.9, 27.5, 27.0, 26.9, 19.6, 19.5, 18.8, 18.7, 18.6, 13.6, 13.5; GC–MS (70 eV, EI): *m*/*z* (rel. int.): ($M^+$ 512< 1%), 137 (100), 95 (16), 81 (57), 69 (11), 55 (5); Anal. Calcd for $C_{31}H_{41}ClO_4$: C, 72.56; H, 8.05. Found: C, 72.64; H, 7.93.

#### 4.6.7. Di-(−)-bornyl-(2*R*)-2-(4-methylphenyl) cyclopropane-1,1-dicarboxylate, 9c

Oil; $[\alpha]_D^{26} = +48.3$ (*c* 2.16, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.12 (d, 2H, *J* = 8.1 Hz), 7.07 (d, 2H, *J* = 8.1 Hz), 5,07 (ddd, 1H, *J* = 2.1, 3.4, 10.0 Hz), 4.54 (ddd, 1H, *J* = 2.1, 3.4, 10.0 Hz), 3.21 (t, 1H, *J* = 8.5 Hz), 2.34–2.37 (m, 1H), 2.30 (s, 3H), 2.22–2.18 (m, 1H), 2.16 (dd, 1H, *J* = 5.0, 8.5 Hz), 1.95–1.90 (m, 1H), 1.85–1.55 (m, 5H), 1.37–1.22 (m, 3H), 1.19–1.08 (m, 3H), 0.94 (s, 3H), 0.89 (s, 3H), 0.90–0.80 (m, 1H), 0.87 (s, 3H), 0.79 (s, 3H), 0.78 (s, 3H), 0.36 (s, 3H); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 170.3, 166.9, 136.8, 131.7, 128.9 (two carbons), 128.3 (two carbons), 81.2, 81.1, 49.0, 48.5, 47.9, 47.6, 44.8, 44.6, 37.9, 36.3, 35.9, 31.6, 28.0, 27.8, 27.1, 26.8, 20.9, 19.7, 19.6, 18.9, 18.8, 18.7, 13.5, 12.6; GC–MS (70 eV, EI): *m*/*z* (rel. int.): 492 ($M^+$<1%), 356 (2), 185 (11), 137 (100), 136 (23), 95 (19), 81 (60), 69 (12), 67 (10). Anal. Calcd for $C_{32}H_{44}O_4$: C, 78.01; H, 9.00. Found: C, 78.12; H, 9.15.

#### 4.6.8. Di-(−)-bornyl-(2*S*)-2-(4-methylphenyl)cyclopropane-1,1-dicarboxylate, 10c

Oil; $[\alpha]_D^{26} = -104.2$ (*c* 2.02, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.12 (d, 2H, *J* = 8.2 Hz), 7.08 (d, 2H, *J* = 8.2 Hz), 5.01 (ddd, 1H, *J* = 2.1, 3.3, 9.8 Hz), 4.55 (ddd, 1H, *J* = 2.2, 3.3, 9.8 Hz), 3.17 (t, 1H, *J* = 8.6 Hz), 2.45–2.37 (m, 1H), 2.31 (s, 3H), 2.13 (dd, 1H, *J* = 5.1, 7.9 Hz), 2.04–1.09 (m, 2H), 1.77–1.65 (m, 4H), 1.63–1.56 (m, 1H), 1.45 (t, 1H, *J* = 4.4 Hz), 1.39–1.26 (m, 3H), 1.17–1.16 (m, 1H), 1.04 (dd, 1H, *J* = 3.4, 13.8 Hz), 0.94 (s, 3H), 0.89 (s, 6H), 0.80 (s, 3H), 0.79 (s, 3H), 0.73 (s, 3H), 0.15 (dd, 1H, *J* = 3.5, 13.9 Hz);$^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 170.0, 166.9, 136.7, 131.6, 128.9 (two carbons), 129.2 (two carbons), 81.6, 81.3, 48.7, 48.3, 47.8, 47.4, 44.6, 44.4, 38.1, 36.7, 35.8, 31.4, 27.9, 27.3, 27.0, 26.8, 20.9, 19.6, 19.5, 18.7, 18.6, 18.4, 13.6, 13.4; GC–MS (70 eV, EI): *m*/*z* (rel. int.): 492 ($M^+$<1%), 356 (2), 185 (10), 137 (100), 136 (22), 95 (19), 81 (59), 69 (12). Anal. Calcd for $C_{32}H_{44}O_4$: C, 78.01; H, 9.00. Found: C, 78.17; H, 9.11.

#### 4.6.9. Di-(−)-bornyl-(2*R*)-2-(4-methoxyphenyl)cyclopropane-1,1-dicarboxylate, 9d

Oil; $[\alpha]_D^{27} = +53.5$ (*c* 2.17, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.15 (d, 2H, *J* = 8.7 Hz), 6.82 (d, 2H, *J* = 8.7 Hz), 5.07 (ddd, 1H, *J* = 2.1, 3.3, 9.9 Hz), 4.54 (ddd, 1H, *J* = 2.1, 3.3, 9.9 Hz), 3.78 (s, 3H), 3.20 (t, 1H, *J* = 8.5 Hz). 2.43–2.37 (m, 1H), 2.21–2.16 (m, 1H), 2.14 (dd, 1H, *J* = 5.0, 8.5 Hz), 1.96–1.89 (m, 1H), 1.78–1.52 (m, 5H), 1.35–1.08 (m, 6H), 0.94 (s, 3H), 0.89 (s, 3H), 0.86 (s, 3H), 0.84 (dd, 1H, *J* = 3.6, 13.9 Hz), 0.79 (s, 3H), 0.78 (s, 3H), 0.40 (s, 3H); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 170.3, 166.9, 158.9, 129.6 (two carbons), 126.8, 113.8 (two carbons), 81.2, 81.1, 55.3, 49.0, 48.5, 47.9, 47.6, 44.8, 44.6, 37.8, 36.3, 35.9, 31.4, 28.0, 27.8, 27.1, 26.8, 19.7, 19.6, 19.0, 18.8, 18.7, 13.5, 12.8; GC–MS (70 eV, EI): *m*/*z* (rel. int.): 508 ($M^+$<1%), 372 (2), 236 (11), 201 (10), 137 (100), 95 (17), 81 (69), 69 (13). Anal. Calcd for $C_{32}H_{44}O_5$: C, 75.56; H, 8.72. Found: C, 75.49; H, 8.84.

#### 4.6.10. Di-(−)-bornyl-(2*S*)-2-(4-methoxyphenyl)cyclopropane-1,1-dicarboxylate, 10d

Oil; $[\alpha]_D^{25} = -93.1$ (*c* 2.88, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.15 (d, 2H, *J* = 8.7 Hz), 6.83 (d, 2H, *J* = 8.7 Hz), 5.01 (ddd, 1H, *J* = 2.2, 3.1, 9.8 Hz), 4.55 (ddd, 1H, *J* = 2.1, 3.1, 9.8 Hz), 3.78 (s, 3H), 3.17 (t, 1H, *J* = 8.4 Hz), 2.44–2.35 (m, 1H), 2.11 (dd, 1H, *J* = 5.1, 7.9 Hz), 2.07–1.84 (m, 2H), 1.80–1.63 (m, 4H), 1.62–1.54 (m, 1H), 1.47 (t, 1H, *J* = 4.4 Hz), 1.34–1.14 (m. 3H), 1.03 (dd, 1H, *J* = 3.4, 13.8 Hz), 0.93 (s, 3H), 0.89 (s, 6H), 0.88–0.85 (m, 1H), 0.80 (s, 3H), 0.79 (s, 3H), 0.73 (s, 3H), 0.17 (dd, 1H, *J* = 3.5, 13.8 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 170.3, 167.1, 158.9, 129.5 (two carbons), 126.8, 113.8 (two carbons), 81.7, 81.4, 55.3, 48.8, 48.4, 47.9, 47.6, 47.7, 44.5, 38.1, 36.1, 35.7, 31.4, 27.9, 27.5, 27.1, 26.9, 19.7, 19.6, 18.8, 18.7, 18.6, 13.6, 13.5; GC-MS (70 eV, EI): *m*/*z* (rel. int.): 508 (1), 372 (1), 236 (9), 201 (15), 137 (100), 95 (22), 81 (62), 69 (14). Anal. Calcd for $C_{32}H_{44}O_5$: C, 75.56; H, 8.72. Found: C, 75.46; H, 8.65.

#### 4.6.11. Di-(−)-menthyl-2-hexylcyclopropane-1,1-dicarboxylate *1 diastereomer*, 9′f

Oil; $[\alpha]_D^{21} = -15.7$ (*c* 1.21, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 4.73 (dt, 1H, *J* = 4.3, 10.9 Hz), 4.68 (dt, 1H, *J* = 4.3,

10.8 Hz), 2.10–2.01 (m, 2H), 1.95 (dsept, 1H, $J$ = 4.2, 6.9 Hz), 1.90–1.78 (m. 2H), 1.74–1.62 (m, 4H), 1.61–1.20 (m, 16H), 1.10–0.95 (m, 4H), 0.94–0.85 (m, 17H), 0.74 (d, 6H, $J$ = 6.9 Hz);$^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 170.3, 168.0, 75.3, 75.2, 47.2, 46.8, 40.8, 40.7, 34.5, 34.3, 34.2, 31.6, 31.3 (two carbons), 28.9 (two carbons), 28.7, 27.8, 26.1, 25.7, 23.4, 22.9, 22.6, 22.1, 22.0, 20.9, 20.8, 20.7, 16.3, 15.8, 14.0; GC–MS (70 eV, EI): $m/z$ (rel. int.): 490 ($M^+$<1%), 215 (63), 214 (78), 138 (49), 117 (23), 110 (54), 97 (20), 95 (27), 83 (100), 81 (33), 69 (37), 57 (27). Anal. Calcd for $C_{31}H_{54}O_4$: C, 75.87; H, 11.09. Found: C, 75.75; H, 11.23.

#### 4.6.12. Di-(−)-menthyl-2-hexylcyclopropane-1,1-dicarboxylate *2 diastereomer*, 10′f

Oil; $[\alpha]_D^{22} = -77.6$ ($c$ 2.48, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 4.78 (dt, 1H, $J$ = 4.4, 10.9 Hz), 4.76 (dt, 1H, $J$ = 4.4, 10.9 Hz), 2.09 (dsept, 1H, $J$ = 4.1, 6.8 Hz), 2.01–1.88 (m, 3H), 1.85–1.75 (m, 1H), 1.73–1.60 (m, 4H), 1.55–1.15 (m, 17H), 1.13–0.96 (m, 4H), 0.93–0.85 (m, 16H), 0.78 (d, 3H, $J$ = 6.9 Hz), 0.76 (d, 3H, $J$ = 6.9 Hz);$^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 170.2, 167.9, 75.2, 75.0, 47.2, 47.0, 40.9, 40.8, 34.4, 34.3, 34.2, 31.7, 31.4 (two carbons), 29.0, 28.9, 28.8, 28.7, 25.8, 25.3, 23.0, 22.7, 22.6, 22.0 (two carbons), 21.2, 21.1, 20.9, 15.9, 15.6, 14.0; MS (70 eV, EI): $m/z$ (rel. int.): 490 ($M^+$<1%), 215 (70), 214 (81), 138 (57), 117 (25), 110 (57), 97 (20), 95 (31), 83 (100), 81 (35), 69 (40), 57 (27). Anal. Calcd for$C_{31}H_{54}O_4$: C, 75.87; H, 11.09. Found: C, 75.72; H, 11.18.

### 4.7. Synthesis of cyclopropane diesters

The synthesis of diesters **12a,b,f** and *ent*-**12a,b,f** as reported in Scheme 5 was carried out according to the procedure described in the literature.[12] The reaction products and the reaction yields are reported in Table 4. The enantiomeric excesses were determined by chiral HPLC and are also reported in Table 4. The spectroscopic data of compounds **12a**,[13a–d] *ent*-**12a**,[13e] and **12b**,[13a,b] were identical to those reported in the literature. Physical and spectroscopic data of compounds **12f** and *ent*-**12f** are reported below.

#### 4.7.1. Dimethyl (2*R*)-2-phenylcyclopropane-1,1-dicarboxylate, 12a

Oil; $[\alpha]_D^{23} = +121.7$ ($c$ 1.62, PhH).[13a–c] HPLC (Chiracel OD-H column (250 × 4.6 ID) eluant: hexane/*i*-PrOH 99:1, flow rate: 0.6 mL/min, UV detection at 230 nm) $t_R$ 20.86 min.

#### 4.7.2. Dimethyl (2*S*)-2-phenylcyclopropane-1,1-dicarboxylate, *ent*-12a

Mp 61–62 °C; $[\alpha]_D^{21} = -114.3$ ($c$ 2.22, PhH).[13c,e] HPLC (Chiracel OD-H column (250 × 4.6 ID) eluant: hexane/*i*-PrOH 99:1, flow rate: 0.6 mL/min, UV detection at 230 nm) $t_R$ 19.50 min.

#### 4.7.3. Dimethyl (2*R*)-2-(4-chlorophenyl)cyclopropane-1,1-dicarboxylate, 12b

Oil; $[\alpha]_D^{21} = +123.3$ ($c$ 1.28, PhH).[13a–b,f] HPLC (Chiracel OD-H column (250 × 4.6 ID) eluant: hexane/*i*-PrOH 99:1, flow rate: 0.8 mL/min, UV detection at 230 nm) $t_R$ 16.24 min.

#### 4.7.4. Dimethyl (2*S*)-2-(4-chlorophenyl)cyclopropane-1,1-dicarboxylate, *ent*-12b

Oil; $[\alpha]_D^{21} = -117.2$ ($c$ 1.23, PhH). HPLC (Chiracel OD-H column (250 × 4.6 ID) eluant: hexane/*i*-PrOH 99:1, flow rate: 0.8 mL/min, UV detection at 230 nm) $t_R$ 15.08 min.

#### 4.7.5. Dimethyl 2-hexylcyclopropane-1,1-dicarboxylate 12f

Oil; $[\alpha]_D^{21} = +53.0$ ($c$ 1.94, PhH). HPLC ((*R*,*R*) Whelk 01 (250 × 4.6 ID), eluant: hexane/*i*-PrOH 99.3:0.7, flow rate: 0.8 mL/min, UV detection at 230 nm) $t_R$ 6.97 min. $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 3.74 (s, 3H), 3.71 (s, 3H), 1.92–1.83 (m, 1H), 1.50–1.33 (m, 5H), 1.32–1.10 (m. 7H), 0.86 (t, 3H, $J$ = 6.4 Hz);$^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 170.9, 168.7, 52.5, 52.3, 33.8, 31.6, 28.9, 28.8, 28.7, 28.6, 22.5, 21.3, 13.9; GC–MS (70 eV, EI): $m/z$ (rel. int.): 242 ($M^+$<1%), 211 (14), 179 (19), 153 (22), 145 (80), 132 (74), 121 (25), 113 (100), 108 (36), 95 (16), 81 (30), 67 (21), 59 (36). Anal. Calcd for $C_{13}H_{22}O_4$: C, 64.44; H, 9.15. Found: C, 64.12; H, 9.01.

#### 4.7.6. 2 Dimethyl 2-hexylcyclopropane-1,1-dicarboxylate, *ent*-12f

Oil; $[\alpha]_D^{22} = -49.0$ ($c$ 1.88, PhH). HPLC ((*R*,*R*) Whelk 01 (250 × 4.6 ID) eluant: hexane/*i*-PrOH 99.3:0.7, flow rate: 0.8 mL/min, UV detection at 230 nm) $t_R$ 6.73 min. NMR and GC–MS are identical to those of compound **12f**. Anal. Calcd for $C_{13}H_{22}O_4$: C, 64.44; H, 9.15. Found: C, 64.29; H, 9.28.

### 4.8. Synthesis of cyclopropane diols

A solution of $LiAlH_4$ 2 M (1.5 mmol) in tetrahydrofuran was added to cyclopropanes **9a,c,d,f** and **10a,c,d,f** (1 mmol) in anhydrous diethyl ether (10 mL) at 0 °C. The reaction mixtures were then stirred for 3 h at room temperature. The reaction mixtures were poured into an aqueous $NH_4Cl$ solution and extracted with diethyl ether. The organic layers were dried over $Na_2SO_4$, filtered, and evaporated under vacuum. Reaction products (Scheme 5) were obtained in a pure form after column chromatography of the residue on silica gel using a mixture of ethyl acetate and light petroleum (50:50) as eluant. The yields and the enantiomeric excesses of compounds **13a,c,d,f** and ***ent*-13a,c,d,f** are reported in Table 4. The physical and spectroscopic data of compounds 1**3a,c,d,f** and ***ent*-13a,c,d,f** are reported below.

#### 4.8.1. [(2*R*)-2-Phenylcyclopropane-1,1-diyl]dimethanol, 13a

Mp 46–48 °C; $[\alpha]_D^{16} = +2.2$ ($c$ 1.75, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.27–7.11 (m, 5H), 3.75 (d, 1H, $J$ = 11.3 Hz), 3.65 (d, 1H, $J$ = 11.3 Hz), 3.53 (d, 1H, $J$ = 11.7 Hz), 3.34 (d, 1H, $J$ = 11.7 Hz), 2.50 (br s, 1H), 2.23 (dd, 1H, $J$ = 6.0, 8.4 Hz), 1.98 (br s, 1H), 1.05 (dd, 1H, $J$ = 5.4, 6.0 Hz), 0.92 (dd, 1H, $J$ = 5.4, 8.4 Hz);$^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 137.6, 128.8 (two carbons), 128.2 (two carbons), 126.3, 69.8, 65.0, 30.6, 26.7, 12.9; MS (70 eV, EI): $m/z$ (rel. int.): 178 (1), 129 (91), 115 (33), 104 (100), 91 (62), 78 (27). Anal. Calcd for $C_{11}H_{14}O_2$: C, 74.13; H, 7.92. Found: C, 74.27; H, 7.82.

#### 4.8.2. [(2*S*)-2-Phenylcyclopropane-1,1-diyl]dimethanol, *ent*-13a

Mp 44–48 °C; $[\alpha]_D^{18} = -2.1$ ($c$ 2.39, $CHCl_3$). Anal. Calcd for $C_{11}H_{14}O_2$: C, 74.13; H, 7.92. Found: C, 74.30; H, 7.91.

#### 4.8.3. [(2*R*)-2-(4-Methylphenyl)cyclopropane-1,1-diyl]dimethanol, 13c

Mp 40–42 °C; $[\alpha]_D^{23} = +9.9$ ($c$ 1.41, $CHCl_3$). HPLC (Chiralpack AD-H column (250 × 4.6 ID), eluant: hexane/*i*-PrOH 96:4, flow rate: 0.8 mL/min, UV detection at 230 nm) $t_R$ 39.02 min. $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.17 (d, 2H, $J$ = 7.1 Hz), 7.12 (d, 2H, $J$ = 7.1 Hz), 3.81 (d, 1H, $J$ = 11.2 Hz), 3.72 (d, 1H, $J$ = 11.2 Hz), 3.62 (d, 1H, $J$ = 11.6 Hz), 3.40 (d, 1H, $J$ = 11.6 Hz), 2.34 (s, 3H), 2.26 (dd, 1H, $J$ = 6.3, 8.1 Hz), 1.92 (br s, 2H), 1.08 (t, 1H, $J$ = 5.8 Hz), 0.96 (dd, 1H, $J$ = 5.4, 8.1 Hz);$^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 136.0, 134.5, 129.1 (two carbons), 128.7 (two carbons), 70.2, 65.5, 30.6, 26.4, 20.9, 12.9; GC–MS (70 eV, EI): $m/z$ (rel. int.): 192 (5), 161 (14), 143 (100), 128 (59), 118 (57), 105 (48), 91 (34), 77 (15). Anal. Calcd for $C_{12}H_{16}O_2$: C, 74.97; H, 8.39. Found: C, 74.86; H, 8.45.

#### 4.8.4. [(2*S*)-2-(4-Methylphenyl)cyclopropane-1,1-diyl]dimethanol, *ent*-13c

Mp 38–40 °C; $[\alpha]_D^{25} = -8.6$ ($c$ 2.42, $CHCl_3$). HPLC (Chiralpack AD-H column (250 × 4.6 ID), eluant: hexane/*i*-PrOH 96:4, flow rate:

0.8 mL/min, UV detection at 230 nm) $t_R$ 42.82 min. Anal. Calcd for $C_{12}H_{16}O_2$: C, 74.97; H,8.39. Found: C, 74.83; H, 8.36.

#### 4.8.5. [(2*R*)-2-(4-Methoxyphenyl)cyclopropane-1,1-diyl]dimethanol, 13d

Mp 84–88 °C; $[\alpha]_D^{30} = +9.1$ (*c* 1.75, $CHCl_3$). HPLC (Chiralpack AD-H column (250 × 4.6 ID), eluant: hexane/*i*-PrOH 90:10, flow rate: 1 mL/min, UV detection at 230 nm) $t_R$ 14.19 min. $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 7.17 (d, 2H, *J* = 8.5 Hz), 6.82 (d, 2H, *J* = 8.5 Hz), 3.79 (d, 1H, *J* = 11.2 Hz), 3.78 (s, 3H), 3.68 (d, 1H, *J* = 11.2 Hz), 3.58 (d, 1H, *J* = 11.6 Hz), 3.37 (d, 1H, *J* = 11.6 Hz), 2.75 (br s, 1H), 2.21 (dd, 1H, *J* = 6.2, 8.5 Hz), 1.75 (br s, 1H), 1.01 (t, 1H, *J* = 5.6 Hz), 0.93 (dd, 1H, *J* = 5.5, 8.5 Hz);$^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 158.1, 129.8 (two carbons), 129.5, 113.7 (two carbons), 70.2, 65.5, 55.2, 30.4, 25.9, 13.0; GC–MS (70 eV, EI): *m*/*z* (rel. int.): 208 (23), 177 (51), 159 (100), 144 (59), 121 (56), 91 (33), 77 (19). Anal. Calcd for $C_{12}H_{16}O_3$: C, 69.21; H, 7.74. Found: C, 69.17; H, 7.83.

#### 4.8.6. [(2*S*)-2-(4-Methoxyphenyl)cyclopropane-1,1-diyl] dimethanol, *ent*-13d

Mp 86–90 °C; $[\alpha]_D^{27} = -9.4$ (*c* 1.21, $CHCl_3$). HPLC (Chiralpack AD-H column (250 × 4.6 ID), eluant: hexane/*i*-PrOH 90:10, flow rate: 1 mL/min, UV detection at 230 nm) $t_R$ 16.09 min. Anal. Calcd for $C_{12}H_{16}O_3$: C, 69.21; H, 7.74. Found: C, 69.16; H, 7.67.

#### 4.8.7. (2-Hexylcyclopropane-1,1-diyl)dimethanol (*from 1 diastereomer*), 13f

Oil; $[\alpha]_D^{21} = +35.8$ (*c* 2.3, $CHCl_3$); $^1$H NMR (400 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 3.82 (d, 1H, *J* = 11.4 Hz), 3.71 (d, 1H, *J* = 11.4 Hz), 3.57 (d, 1H, *J* = 11.1 Hz), 3.52 (d, 1H, *J* = 11.1 Hz), 2.78 (br s, 2H), 1.55–1.47 (m, 1H), 1.43–1.19 (m, 9H), 0.88 (t, 3H, *J* = 6.7 Hz), 0.85–0.72 (m, 1H), 0.60 (dd, 1H, *J* = 4.8, 8.5 Hz), 0.21 (t, 1H, *J* = 5.2 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$, 25 °C, TMS): $\delta$ 71.2, 65.7, 31.8, 30.0, 29.1, 28.9, 27.6, 22.7, 22.6, 14.8, 14.0; MS (70 eV, EI): *m*/*z* (rel. int.): 186 ($M^+$<1%), 130 (100), 129 (62), 115 (15), 75 (14). Anal. Calcd for $C_{11}H_{22}O_2$: C, 70.92; H, 11.90. Found: C, 70.76; H, 11.69.

#### 4.8.8. (2-Hexylcyclopropane-1,1-diyl)dimethanol (*from 2 diastereomer*), *ent*-13f

Oil; $[\alpha]_D^{21} = -33.8$ (*c* 2.3, $CHCl_3$); Anal. Calcd for $C_{11}H_{22}O_2$: C, 70.92; H, 11.90. Found: C, 71.09; H, 11.97.

### 4.9. Synthesis of cyclopropane α-amino acids (ACCs)

The synthesis of ACCs **14a** and ***ent*-14a** reported in Scheme 6 was effected according to the procedure described in the literature.[13c,16a] The reaction products and the reaction yields are reported in Scheme 6. The physical and spectroscopic data are identical to those reported in the literature.[13c,16b]

#### 4.9.1. Methyl (1*S*,2*R*)-1-[(*tert*-butoxycarbonyl)amino]-2-phenylcyclopropanecarboxylate 14a

Oil; $[\alpha]_D^{21} = -80.5$ (*c* 1.82, $CHCl_3$).[13c]

#### 4.9.2. Methyl (1*R*,2*S*)-1-[(*tert*-butoxycarbonyl)amino]-2-phenylcyclopropanecarboxylate *ent*-14a

Oil; $[\alpha]_D^{25} = -79.2$ (*c* 1.35, $CHCl_3$).[13c]

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