Synthesis of the Insect Pheromone (2*S*,3*S*,7*RS*)-Diprionyl Acetate by Diastereoselective Protonation

Sophia Ebert[a] and Norbert Krause*[a]

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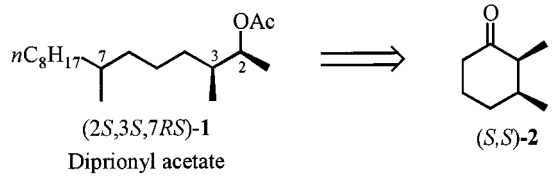
The insect pheromone (2*S*,3*S*,7*RS*)-diprionyl acetate (**1**) was prepared from (*S*,*S*)-2,3-dimethylcyclohexanone (**2**), which in turn was obtained by the 1,4-addition of lithium dimethylcuprate to (*S*)-(+)-carvone (**3**) and diastereoselective protonation of the resulting enolate with phenyl salicylate, followed by removal of the isopropenyl group and hydrogenation. Baeyer–Villiger rearrangement of (*S*,*S*)-**2** and opening of the lactone (*S*,*S*)-**8** with octyllithium provided the hydroxy ketone (*S*,*S*)-**9**, which was transformed into the target molecule (2*S*,3*S*,7*RS*)-**1** by carbonyl olefination with Petasis' reagent, acylation and hydrogenation.

Introduction

The sawflies (*hymenoptera: Diprionidae*) belong to the most common pine pests of Northern Europe, Asia and North America. Esters of diprionol (3,7-dimethyl-2-pentadecanol) have been identified by Jewett et al.[1] as pheromones of these insects; diprionyl acetate (**1**) is the attractant of the *Neodiprion* species whereas the corresponding propionate was found in the *Diprion* sawflies. Among about 85 species of diprionid sawflies, the pine sawfly *Neodiprion sertifer* has been examined with particular intensity.[2] Biological studies have shown that (*S*,*S*,*S*)-3,7-dimethyl-2-pentadecanyl acetate is the most active of the eight stereoisomers, and this is also the only isomer to be isolated from the insect.[3] (2*S*,3*S*,7*R*)-Diprionyl acetate is somewhat less active whereas all other stereoisomers show no detectable pheromone activity. Thus, the absolute and relative configuration at C-2 and C-3 is highly important for the biological activity whereas the configuration at C-7 is of little relevance.[4] (*S*,*S*,*S*)-3,7-Dimethyl-2-pentadecanyl acetate is also the most active isomer of *Neodiprion namulus namulus*, *N. lecontei* and *N. pinetum*;[5] in contrast, (2*S*,3*R*,7*R*)-diprionyl propionate was identified as most active pheromone of *Diprion similis*.[6]

Due to the strong dependence of the pheromone activity on the absolute and relative configuration, the stereoselective synthesis of diprionyl acetate is of great interest and should allow its use as a pest control agent in pheromone traps. Several diastereo-[7] and enantioselective[8] syntheses of the isomers of 3,7-dimethyl-2-pentadecanyl acetate have already been described; the latter make use of readily available chiral starting materials like citronellol, tartaric acid and proline, but are rather long. A very straightforward synthesis of racemic diprionyl acetate was described by Magnusson[7a,7b] starting from 2,3-dimethylcyclohexanone (**2**) whereby *cis*-**2** furnished the pheromone with a (2*RS*,3*RS*)-configuration (Scheme 1). Thus, an efficient enantioselective synthesis of (2*S*,3*S*,7*RS*)-diprionyl acetate should be possible following this route when starting with (*S*,*S*)-2,3-dimethylcyclohexanone. In this paper, we describe the realization of this synthesis, making use of the highly diastereoselective protonation of chiral enolates with chelating proton sources developed by us.[9] The method was also applied to the diastereoselective synthesis of (±)-methyl epijasmonate and (±)-methyl dihydroepijasmonate.[10]



(2*S*,3*S*,7*RS*)-**1**
Diprionyl acetate

(*S*,*S*)-**2**

Scheme 1

Results and Discussion

One of the most efficient and selective routes to *cis*-2,3-disubstituted cycloalkanones makes use of the chelate-controlled diastereoselective protonation of chiral metal enolates with salicylates as proton source.[9] Thus, 2,3-dimethylcyclohexanone is accessible with a *cis*:*trans* ratio of 96:4 by 1,4-addition of lithium dimethylcuprate to 2-methyl-2-cyclohexenone and subsequent protonation with ethyl salicylate.[9a] In the context of Magnusson's work,[7a,7b] this already constitutes a formal synthesis of racemic diprionyl acetate with the desired relative configuration at C-2 and C-3.

Our enantioselective synthesis of (2*S*,3*S*,7*RS*)-diprionyl acetate (**1**) started with the commercially available chiral enone (*S*)-(+)-carvone (**3**); Michael addition of lithium dimethylcuprate and enolate protonation with phenyl salicylate (**4**) provided (*S*,*S*,*S*)-**5** with 80% chemical yield, 98% *ds* and >99% *ee* (Scheme 2). Whereas methyl or ethyl salicylate gave similar diastereoselectivities,[9b,9c] the use of the less volatile phenyl ester facilitated the separation of product

[a] Lehrstuhl für Organische Chemie II, Universität Dortmund, 44221 Dortmund, Germany
Fax: (internat.) +49-231/755-3884
E-mail: nkrause@pop.uni-dortmund.de

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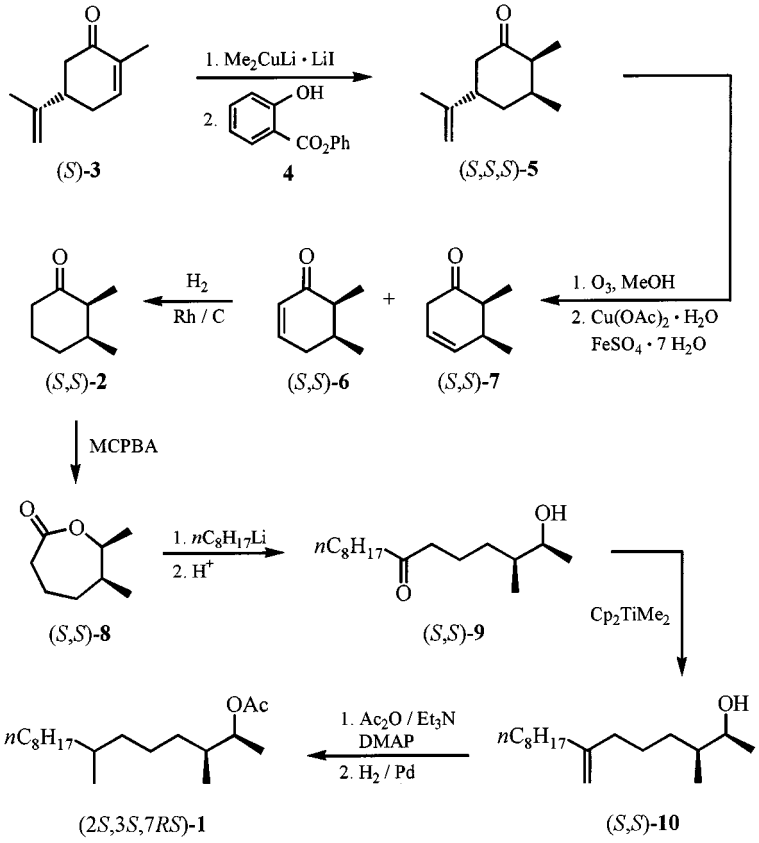

Scheme 2

and proton source by simple distillation. It should be noted here that **5** can be obtained with up to 93% *ds* by using the polymeric chelating proton donors developed by us;[9c] in this case, the separation is carried out by filtration.

In order to remove the isopropenyl group from ketone (*S*,*S*,*S*)-**5**, we made use of a Criegee rearrangement. Ozonation of **5** in methanol, followed by treatment of the peroxy ester with cupric acetate and ferric sulfate[11] gave rise to the formation of the enones (*S*,*S*)-**6** and (*S*,*S*)-**7** with 43% and 13% yield, respectively (Scheme 2). Both products were obtained with 98% *ds* and >98% *ee* and could be converted into (*S*,*S*)-2,3-dimethylcyclohexanone (**2**) by catalytic hydrogenation. The use of palladium on charcoal as the hydrogenation catalyst in diethyl ether, however, caused considerable epimerization at C-2 to give large amounts of *trans*-**2**. This isomerization could be prevented by using ethyl acetate as solvent, but in this case 2,3-dimethylcyclohexanol was formed as a side product. The catalyst of choice turned out to be rhodium on charcoal in petroleum ether, giving (*S*,*S*)-**2** with high chemical yield, 95−96% *ds* and >99% *ee*.

For the remaining steps from (*S*,*S*)-**2** to the target molecule (2*S*,3*S*,7*RS*)-diprionyl acetate (**1**) we intended to follow Magnusson's synthesis.[7a,7b] The regioselective Baeyer−Villiger oxidation of (*S*,*S*)-**2** to the lactone (*S*,*S*)-**8**[12] (74% yield) and the subsequent ring opening with octyllithium (prepared from 1-iodooctane by halogen-metal exchange with *t*BuLi[13]) to give the hydroxy ketone (*S*,*S*)-**9** proceeded uneventfully. The following carbonyl olefination, however, turned out be difficult due to the low reactivity of this substrate, and we were unable to reproduce the yield of 66% obtained by Magnusson[7a,7b] with the Wittig reagent $Ph_3P{=}CH_2$. Here, Petasis' reagent Cp_2TiMe_2 [14] turned out to be a useful alternative, giving the desired product (*S*,*S*)-**10** with 60% yield [with regard to (*S*,*S*)-**8**] and 98% *ds*. Finally, acylation (95% yield) and (non-stereoselective) hydrogenation with palladium on charcoal as catalyst (93% yield) provided the target molecule (2*S*,3*S*,7*RS*)-diprionyl acetate (**1**). The diastereomeric purity (with regard to C-2 and C-3) could be determined by gas chromatography on Carbowax to be 98% (no splitting of the GC peaks because of the presence of two diastereomers with regard to the stereogenic center at C-7 was observed). The low volatility of the product, however, prevented the determination of the enantiomeric excess with a cyclodextrin GC column. An enantiomeric purity of at least 95% *ee* was determined by NMR spectroscopy in the presence of $Eu(hfc)_3$ as a chiral shift reagent.

Conclusion

In this paper, we describe the diastereo- and enantioselective synthesis of the insect pheromone (2*S*,3*S*,7*RS*)-diprionyl acetate (**1**) from (*S*,*S*)-2,3-dimethylcyclohexanone (**2**), which was obtained by 1,4-addition of lithium di-

methylcuprate to (*S*)-(+)-carvone (**3**) and diastereoselective protonation of the resulting enolate with phenyl salicylate, followed by removal of the isopropenyl group and hydrogenation. Baeyer−Villiger rearrangement of (*S*,*S*)-**2** and opening of the lactone (*S*,*S*)-**8** with octyllithium provided the hydroxy ketone (*S*,*S*)-**9**, which was transformed into the target molecule (2*S*,3*S*)-**1** by carbonyl olefination with Petasis' reagent, acylation and hydrogenation. The sequence is not selective with regard to the stereogenic center at C-7; however, this is of no practical consequence since the pheromone activity is hardly affected by the configuration at this position.

Our enantioselective synthesis of diprionyl acetate by diastereomeric protonation is competitive with, if not superior to, previous enantioselective preparations of this pheromone,[8] because it starts from a cheap, commercially available terpene and does not require any other chiral reagent or building block. The method can also be applied to the synthesis of other stereoisomers of **1** since carvone (**3**) is readily available in both enantiomeric forms; likewise, insect pheromones with branched or shorter chains[15] are accessible by reacting lactone (*S*,*S*)-**8** with the appropriate organolithium reagent.

Experimental Section

General Information: NMR spectra were recorded with a Bruker WM 400 spectrometer at 400 MHz (^{1}H) and 100.6 MHz (^{13}C) in $CDCl_3$ as solvent and internal standard (δ = 7.27 for ^{1}H, δ = 77.05 for ^{13}C). The signals of a major component of a product mixture are marked with an asterisk (*). IR spectra were obtained with a Perkin−Elmer 1600 FT-IR spectrometer, and mass spectra with A.E.I. MS-30 and MS-50 spectrometers (EI, 70 eV). GC-MS spectra were recorded with a Hewlett Packard HP 5850 Series II spectrometer. GC analyses were carried out with a Dani 86.10 or a Carlo Erba GC 8000 gas chromatograph with hydrogen as carrier gas and an OV-1701 capillary column. Elemental analyses were obtained with Perkin−Elmer CHN 240 A and B analyzers. The reactions were carried out in thoroughly dried glassware under argon. Diethyl ether was distilled from $LiAlH_4$ prior to use. MeLi, and *t*BuLi were titrated with diphenylacetic acid according to the procedure of Kofron and Baclawski.[16]

(*S*,*S*,*S*)-2,3-Dimethyl-5-(2-propen-2-yl)-cyclohexanone (5): MeLi (1.6 M solution in diethyl ether; 94 mL, 0.15 mol) was added dropwise at −20 °C to a suspension of CuI (14.3 g, 75.0 mmol) in 300 mL of diethyl ether. The resulting clear cuprate solution was stirred at −20 °C for 5 min., cooled to −80 °C, and (*S*)-carvone (**3**; 7.51 g, 50.0 mmol) in 100 mL of diethyl ether was added dropwise. The mixture was warmed to −30 °C within 1 h and then again cooled to −80 °C. It was then transferred through a Teflon tube into a solution of phenyl salicylate (**4**; 42.8 g, 0.2 mol) in 300 mL of diethyl ether which was also kept at −80 °C. The mixture was warmed to room temperature, and 11.5 mL (0.2 mol) of acetic acid was added. After filtration through Celite® the filtrate was washed twice with a satd. $NaHCO_3$ solution and dried with $MgSO_4$. Removal of the solvent in vacuo was followed by distillation of the crude product, furnishing 6.62 g (80%) of (*S*,*S*,*S*)-**5** as a colorless liquid (bp^{13} = 110 °C). The diastereomeric purity was determined by GC to be 98%. − ^{1}H NMR (C_6D_6): δ = 0.61 (d, *J* = 7.1 Hz, 2-Me), 0.97 (d, *J* = 6.9 Hz, 3-Me), 1.45 (m, 2 H), 1.48 (s, 3 H, 3′-H), 1.80−1.92 (m, 2 H), 2.09 (m, 1 H), 2.36 (m, 2 H), 4.65 (s, 1 H, 1′-H), 4.71 (s, 1 H, 1′-H). − ^{13}C NMR (C_6D_6): δ = 12.3 (+, 2-Me), 13.9 (+, 3-Me), 20.5 (+, C-3′), 36.2 (+, C-3), 37.8 (−, C-4), 41.1 (+, C-5), 46.7 (−, C-6), 48.1 (+, C-2), 109.8 (−, C-1′), 147.8 (x, C-2′), 209.9 (x, C-1). − IR (neat): $\tilde{\nu}$ = 3082 cm^{-1} (s), 2989 (s, C−H), 1711 (s, C=O), 1453 (s). − MS: *m*/*z* (%) = 166 (75) [M$^+$], 151 (10) [M − Me], 95 (50), 69 (100). − HRMS calcd. for $C_{11}H_{18}O$ 166.1366; found 166.1362.

(*S*,*S*)-5,6-Dimethyl-2-cyclohexenone (6) and (*S*,*S*)-5,6-Dimethyl-3-cyclohexenone (7): Ozone was passed through a solution of (*S*,*S*,*S*)-**5** (6.62 g, 39.8 mmol) in 100 mL of dry methanol for 1.5 h whilst cooling between −10° and −40 °C. The slightly blue solution was then purged with argon for 10 min., and $Cu(OAc)_2{\cdot}H_2O$ (16.0 g, 80.0 mmol) was added whilst stirring at −20 °C. After 15 min., $FeSO_4{\cdot}7H_2O$ (13.3 g, 48.0 mmol) was added, and the mixture was warmed slowly to room temperature. After stirring for 18 h, water was added and the mixture was washed five times with diethyl ether. The combined organic phases were washed with a satd. $NaHCO_3$ solution, brine, and water and dried with $MgSO_4$. After removal of the solvent in vacuo the crude product was purified by column chromatography (SiO_2, petroleum ether/*tert*-butyl methyl ether, 10:1), providing 2.11 g (43%) of (*S*,*S*)-**6** and 0.62 g (13%) of (*S*,*S*)-**7** as colorless liquids. GC analysis with Lipodex E revealed diastereomeric ratios of 98:2 and enantiomeric excesses of > 98% *ee* for both products.

(*S*,*S*)-6: ^{1}H NMR (C_6D_6): δ = 0.59 (d, *J* = 6.9 Hz, 3 H, 6-Me), 0.92 (d, *J* = 7.1 Hz, 3 H, 5-Me), 1.52−1.76 (m, 3 H, 4-H, 5-H), 2.22 (dq, *J* = 4.2/7.1 Hz, 1 H, 6-H), 5.90 (dt, *J* = 14.3/2.0 Hz, 1 H, 2-H), 6.13 (m, 1 H, 3-H). − ^{13}C NMR (C_6D_6): δ = 11.0 (+, 6-Me), 15.2 (+, 5-Me), 31.9 (−, C-4), 33.6 (+, C-5), 46.4 (+, C-6), 129.0 (+, C-2), 146.7 (+, C-3), 201.2 (x, C-1). − IR (neat): $\tilde{\nu}$ = 3030 cm^{-1} (s), 2970 (s, C−H), 1683 (s, C=O). − MS: *m*/*z* (%) = 124 (15) [M$^+$], 96 (20), 68 (100).

(*S*,*S*)-7: ^{1}H NMR (C_6D_6): δ = 0.64 (d, *J* = 7.1 Hz, 3 H, 6-Me), 0.95 (d, *J* = 6.9 Hz, 3 H, 5-Me), 2.17 −2.53 (m, 4 H, 2-H, 5-H, 6-H), 5.28 (m, 1 H, 3-H), 5.55 (m, 1 H, 4-H). − ^{13}C NMR (C_6D_6): δ = 11.0 (+, 6-Me), 15.2 (+, 5-Me), 37.9 (+, C-5), 40.2 (−, C-2), 47.0 (+, C-6), 123.4 (+, C-3), 133.6 (+, C-4), 208.9 (x, C-1). − IR (neat): $\tilde{\nu}$ = 3029 cm^{-1} (s), 2970 (s, C−H), 1715 (s, C=O). − MS: *m*/*z* (%) = 124 (35) [M$^+$], 96 (35), 68 (100). − HRMS calcd. for $C_8H_{12}O$ 124.0884; found 124.0886.

(*S*,*S*)-2,3-Dimethylcyclohexanone (2):[7a,7b] A solution of (*S*,*S*)-**6** (621 mg, 5.0 mmol) in 50 mL of petroleum ether was treated with 60 mg of rhodium on charcoal (5%) and hydrogenated at ambient pressure for 3 h. The catalyst was filtered off and the solvent was removed in vacuo, giving 570 mg (90%) of (*S*,*S*)-**2** as a colorless liquid. GC analysis with Lipodex E showed a *cis*:*trans* ratio of 96:4 and an enantiomeric excess of >99% *ee* for the *trans* isomer. The analogous reaction of 124 mg (1.0 mmol) of (*S*,*S*)-**7** provided 101 mg (80%) of (*S*,*S*)-**2** with *cis*:*trans* = 95:5 and > 99% *ee*. − $[\alpha]_D^{24}$ = +28.3 (*c* = 3.39, chloroform).

(*S*,*S*)-6,7-Dimethyl-2-oxepanone (8):[7a,7b] A solution of MCPBA (2.40 g, 11.8 mmol) (85%) in 40 mL of dichloromethane was added dropwise at room temperature to (*S*,*S*)-**2** (1.03 g, 8.2 mmol) in 30 mL of dichloromethane. The mixture was stirred for 16 h, the precipitate was filtered off, and the filtrate was washed twice with a satd. $NaHCO_3$ solution and dried with $MgSO_4$. Purification of the crude product obtained after removal of the solvent in vacuo by column chromatography (SiO_2, cyclohexane/diethyl ether, 3:2) gave 860 mg (74%) of (*S*,*S*)-**8** as a colorless liquid. GC analysis revealed a *cis*:*trans* ratio of ≥96:4. − ^{1}H NMR ($CDCl_3$): δ = 0.95

(d, J = 7.4 Hz, 3 H, 6-Me), 1.34 (d, J = 6.6 Hz, 3 H, 7-Me), 1.75 (m, 4 H), 1.95 (m, 1 H), 2.55−2.65 (m, 2 H), 4.60 (q, J = 6.6 Hz, 1 H, 7-H). − ^{13}C NMR ($CDCl_3$): δ = 10.4 (+, 6-Me), 17.9 (−, C-4), 20.1 (+, 7-Me), 34.7, 35.1 (2-, C-3, C-5), 36.1 (+, C-6), 78.3 (+, C-7), 175.5 (x, C-2).

(*S*,*S*)-2-Hydroxy-3-methyl-7-pentadecanone (9):[7a,7b] *t*BuLi (1.6 M solution in pentane; 7.2 mL, 11.5 mmol) was added dropwise at −80 °C to a solution of 1-iodootane (1.26 g, 5.2 mmol) in 30 mL of diethyl ether, and the mixture was stirred for 1 h at −80 °C and a further hour at room temperature. The solution was again cooled to −80 °C and added via a Teflon tubing to a solution of (*S*,*S*)-**8** (711 mg, 5.0 mmol) in 10 mL of diethyl ether which was also kept at −80 °C. The mixture was warmed to −20 °C and hydrolyzed with 1 N HCl. The organic layer was removed, and the aqueous layer was washed three times with diethyl ether. The combined organic phases were washed with a satd. $NaHCO_3$ solution and dried with $MgSO_4$. The solvent was removed, and the crude product was used without purification in the next reaction. GC analysis showed a diastereomeric purity of 98%. − ^{1}H NMR ($CDCl_3$): δ = 0.82 (m, 6 H, 3-Me, 15-H), 1.07 (d, J = 6.4 Hz, 3 H, 1-H), 1.20 (m, 12 H), 1.32−1.60 (m, 7 H), 2.32 (m, 3 H), 3.67 (dq, J = 4.4/6.4 Hz, 1 H, 2-H). − ^{13}C NMR ($CDCl_3$): δ = 14.0, 14.1 (2+, 3-Me, C-15), 20.2 (+, C-1), 21.5, 22.7, 23.9, 29.2, 29.3, 29.4, 31.8, 32.2 (8-, C-4, C-5, C-9, C-10, C-11, C-12, C-13, C-14), 39.6 (+, C-3), 42.9, 42.9 (2-, C-6, C-8), 71.0 (+, C-2), 211.7 (x, C-7).

(*S*,*S*)-3-Methyl-7-octyl-7-octen-2-ol (10):[7a,7b] Cp_2TiMe_2 (0.45 M solution in toluene; 2.7 mL, 1.2 mmol) was added to a solution of (*S*,*S*)-**9** (103 mg, 0.40 mmol) in 30 mL of toluene, and the mixture was heated to 65 °C for 8 h. After addition of another 1.8 mL (0.8 mmol) of the Cp_2TiMe_2 solution, the mixture was heated further to 65 °C for 8 h. After cooling to room temperature, 60 mL of petroleum ether was added, and the precipitate was filtered off. The solvent was removed from the filtrate in vacuo, and the product was again treated with petroleum ether and filtered. Removal of the solvent from the filtrate in vacuo furnished a yellow oil which was purified by column chromatography (SiO_2, petroleum ether/*tert*-butyl methyl ether, 10:1), providing 61 mg (60%) of (*S*,*S*)-**10** as a colorless oil with a diastereomeric purity of 98% (GC analysis). − ^{1}H NMR ($CDCl_3$): δ = 0.83 (m, 6 H, 3-Me, 8′-H), 1.09 (d, J = 6.4 Hz, 3 H, 1-H), 1.22 (m, 12 H), 1.30−1.45 (m, 6 H), 1.93 (m, 4 H), 3.65 (m, 1 H, 2-H), 4.64 (s, 2 H, 8-H). − ^{13}C NMR ($CDCl_3$): δ = 14.1, 14.2 (2+, 3-Me, C-8′), 20.3 (+, C-1), 22.7, 25.5, 27.8, 29.3, 29.5, 29.6, 31.9, 32.4 (8-, C-4, C-5, C-2′, C-3′, C-4′, C-5′, C-6′, C-7′), 36.1, 36.3 (2-, C-6, C-1′), 39.7 (+, C-3), 71.4 (+, C-2), 108.6 (−, C-8), 150.2 (x, C-7).

(*S*,*S*)-3-Methyl-7-octyl-7-octen-2-yl acetate:[7a,7b] A mixture of (*S*,*S*)-**10** (76 mg, 0.30 mmol), acetic anhydride (0.2 mL, 2.0 mmol), Et_3N (0.3 mL, 2.0 mmol), and DMAP (49 mg, 0.4 mmol) in 20 mL of diethyl ether was stirred for 5 h at room temperature. The mixture was then diluted with water, the organic layer was separated, and the aqueous layer was washed three times with diethyl ether. The combined organic phases were dried with $MgSO_4$, the solvent was removed in vacuo, and the crude product was purified by column chromatography (SiO_2, petroleum ether/*tert*-butyl methyl ether, 20:1), yielding 84 mg (95%) of (*S*,*S*)-3-methyl-7-octyl-7-octen-2-yl acetate as a colorless oil with a diastereomeric purity of 98% (GC analysis). − ^{1}H NMR ($CDCl_3$): δ = 0.83 (m, 6 H, 3-Me, 8′-H), 1.10 (d, J = 6.4 Hz, 3 H, 1-H), 1.22 (m, 11 H), 1.30−1.45 (m, 5 H), 1.53 (m, 1 H), 1.93 (m, 4 H), 1.97 (s, 3 H, MeCO), 4.65 (d, J = 3.7 Hz, 2 H, 8-H), 4.76 (dq, J = 4.9/6.4 Hz, 1 H, 2-H). − ^{13}C NMR ($CDCl_3$): δ = 14.1, 14.8 (2+, 3-Me, C-8′), 16.9 (+, C-1), 21.4 (+, *Me*CO), 22.7, 25.2, 27.8, 29.3, 29.4, 29.5, 31.9, 32.1 (8-, C-4, C-5, C-2′, C-3′, C-4′, C-5′, C-6′, C-7′), 36.0, 36.2, (2-, C-6, C-1′), 37.5 (+, C-3), 74.1 (+, C-2), 108.6 (−, C-8), 150.0 (x, C-7), 170.8 (x, Me*C*O).

(2*S*,3*S*)-3,7-Dimethyl-2-pentadecanyl acetate (1):[7,8] A solution of (*S*,*S*)-3-methyl-7-octyl-7-octen-2-yl acetate (60 mg, 0.20 mmol) in 15 mL of diethyl ether was treated with 10 mg of palladium on charcoal (10%) and hydrogenated at ambient pressure for 3 h. The catalyst was filtered off and the solvent was removed in vacuo, giving 56 mg (93%) of (2*S*,3*S*)-**1** as a colorless liquid. GC analysis revealed a diastereomeric purity of 98%, and the enantiomeric excess was determined by ^{1}H NMR spectroscopy with Eu(hfc)$_3$ as >95% *ee*. − ^{1}H NMR ($CDCl_3$): δ = 0.80 (m, 9 H, 3-Me, 7-Me, 15-H), 1.00 (m, 3 H), 1.10 (d, J = 6.4 Hz, 3 H, 1-H), 1.15−1.30 (m, 18 H), 1.52 (m, 1 H), 1.96 (s, 3 H, MeCO), 4.76 (m, 1 H, 2-H). − ^{13}C NMR ($CDCl_3$): δ = 14.1, 14.8 (2+, 3-Me, C-15), 16.9 (+, C-1), 19.6 (+, 7-Me), 21.4 (+, *Me*CO), 22.7, 24.5, 27.1, 29.4, 29.7, 30.0, 31.9, 32.7 (8-, C-4, C-5, C-9, C-10, C-11, C-12, C-13, C-14), 37.2, 37.3, (2-, C-6, C-8), 37.6, 37.6 (2+, C-3, C-7), 74.1 (+, C-2), 170.9 (x, Me*C*O).

Acknowledgments

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