



Asymmetric Synthesis, Characterization and Stereoselectivity of Novel 1-[2-[(1R,2S)-2-(Chloromethyl)cyclopropyl]ethyl]-4-methoxybenzene via Boronate Complex

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Novel 1-[2-[(1R,2S)-2-(chloromethyl)cyclopropyl]ethyl]-4-methoxybenzene was synthesized by cyclopropanation reaction through a novel route. Carbamate was reacted with 2-allyl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane to form boronic ester which was further treated with 1-bromo-3,5-bis(trifluoromethyl)benzene in the presence of *n*-BuLi and nucleophilic boronate complex was synthesized. 1-[2-[(1R,2S)-2-(chloromethyl)cyclopropyl]ethyl]-4-methoxybenzene was then prepared by reacting boronate complex with different electrophiles like trichloroisocyanuric acid (TCCA) and N-chlorosuccinimide (NCS). Yields and diastereomeric ratios (d.r) were studied by using various aryl lithiums and electrophiles at different temperatures. Best yield, diastereomeric ratio (d.r), enantiomeric ratio (e.r), enantiomeric excess (e.e), enantiospecificity and $[\alpha]_D$ were 67 %, 2.1:1, 68.6:28.9, 39.7, 0.41 and +3.84, respectively.

Keywords: Boronic ester, Boronate complex, Aryllithium, Electrophiles, Cyclopropanation, Stereoselectivity.

INTRODUCTION

In the past decade, there has been great interest in the development of catalytic enantioselective methods for the preparation of chiral, optically enriched organoboronates as precursors of enantio-enriched compounds. There is a wide use of organometallic nucleophiles in organic synthesis but there are a few chiral examples of these useful reagents. Organic synthesis usually involves combination of many nucleophiles with electrophiles. Boronate complexes containing stereogenic boron act as nucleophiles¹ and were synthesized by reacting trivalent borons with different nucleophiles^{2,3}. Kaiser *et al.*⁴ prepared boronate complex (99 % e.e) without racemization at boron through chirality transfer from a carbon. Chang *et al.*⁵ synthesized chiral alkylboronates in high yields and 98 % e.e by reacting Grignard reagent with unsaturated esters and thioesters. Gauthier *et al.*¹ converted boronic esters into reactive nucleophiles and resulting boronate complexes were reacted with a number of electrophiles with inversion of stereochemistry. Lou *et al.*⁶, Chong *et al.*⁷ and Goodman and Pellegrinet⁸ synthesized reactive boronate species by replacing alkoxy groups with biphenols. Vedejs *et al.*⁹ converted many amino acids into asymmetric boronate complexes. Boronate complexes had been used as reaction intermediates for the synthesis of many useful asymmetric products. Lessard *et al.*¹⁰ reacted chiral allylic boronate to various aldehydes and synthesized useful α -hydroxyalkyl derivatives in high stereoselectivity. Hall

*et al.*¹¹ prepared many alcohols and amines from alkyl boronates in good yields.

In recent study, we developed a novel route for the synthesis of novel 1-[2-[(1R,2S)-2-(chloromethyl)cyclopropyl]ethyl]-4-methoxybenzene (**9**) by using boronate complexes as nucleophiles. Boronic esters were converted into reactive nucleophilic boronate complexes by reacting with some aryl lithium and after combining with certain electrophiles desired product was obtained. Reaction was investigated at different temperatures using various aryllithiums and electrophiles to get the best yields and stereoselectivity. High yields and d.r were obtained by tuning the temperature with different aryl lithium and electrophiles like trichloroisocyanuric acid (TCCA) and N-chlorosuccinimide (NCS).

EXPERIMENTAL

N,N-Diisopropylcarbamoyl chloride, 3-(4-methoxyphenyl)-1-propanol, *n*-butyl lithium (*n*-BuLi), *sec*-butyl lithium solution (*s*-BuLi) (1.6 M), allylboronic acid pinacol ester, (-) sparteine, N,N,N,N-tetramethyl-ethylenediamine (TMEDA), 1,3-bis(trifluoromethyl)-5-bromobenzene, 1-bromonaphthalene, N-chlorosuccinimide (NCS) and trichloroisocyanuric acid (TCCA) were purchased from Sigma Aldrich while triethylamine was purchased from Fischer. All chemicals were used as such as received. Anhydrous dichloromethane (DCM), diethyl ether, acetonitrile and tetrahydrofuran (THF) were obtained after distillation with sodium benzophenone

ketyl under nitrogen and stored in Young's flasks over 4 Å molecular sieves. N,N,N,N-tetramethylethylene-diamine (TMEDA) was distilled over CaH₂. Being air and water sensitive, all reactions were carried out in flame-dried glass-ware under nitrogen atmosphere using standard Schlenk lines.

Synthesis of 3-(4-methoxyphenyl)propyl-N,N-diisopropylcarbamate (4): Triethylamine (Et₃N) (5 mL, 36.1 mmol, 1.2 eq) (3) was added to a solution of N,N-diisopropylcarbamoyl chloride (5.43 g, 33.1 mmol, 1.1 eq.) (1) and 3-(4-methoxyphenyl)-1-propanol (5 g, 30.1 mmol, 1.0 eq.) (2) in CH₂Cl₂ (30 mL) at room temperature. The resulting mixture was refluxed for 16 h, allowed to cool to room temperature and quenched with 1 N NaOH (50 mL). The layers were separated and the aqueous phase was extracted with CH₂Cl₂. The combined organic layers were washed with 1 N HCl, water and brine, dried (MgSO₄), concentrated and purified by column chromatography (SiO₂, 90:10 petrol/EtOAc) to obtain the desired 3-(4-methoxyphenyl)propyl-N,N-diisopropylcarbamate (4) (8.69 g, 99 %) as white solid (Fig. 1.)

Carbamate (4) was characterized through ¹H NMR, ¹³C NMR and functional groups were confirmed through IR. This crude product (4) was used for the synthesis of (R)-2-(1-(4-methoxyphenyl)hex-5-en-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (6) and 2-(1-(4-methoxyphenyl)hex-5-en-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (7).

¹H NMR (400 MHz, CDCl₃) δ ppm 7.10 (2H, d, *J* = 8.80 Hz, 2 × *ArH*) 6.83 (2H, d, *J* = 8.80 Hz, 2 × *ArH*) 4.10 (2H, t, *J* = 6.5 Hz, OCH₂) 3.96 (2H, br s, 2 × -CH(CH₃)₂) 3.78 (3H, s, OCH₃) 2.62-2.69 (2H, m, CH₂CH₂CH₂O) 1.90-1.98 (2H, m, CH₂CH₂CH₂O) 1.22 (12H, d, *J* = 6.85 Hz, 4 × CH₃) ¹³C NMR (100 MHz, CDCl₃) δ ppm 157.8 (1C, NCOO), 155.8 (1C, ArC), 133.6 (1C, ArC), 129.3 (2C, 2 × ArCH), 113.8 (2C, 2 × ArCH), 64.0 (1C, CH₂CH₂CH₂O), 55.2 (1C, OCH₃), 45.8 (2C, br, 2 × CH(CH₃)₂), 31.6 (1C, CH₂CH₂CH₂O), 31.1 (1C, CH₂CH₂CH₂O), 21.0 (4C, br, 4 × CH₃). IR (film): ν(cm⁻¹) 3026 (*sp*² C-H Stretch), 2967, 2868 (*sp*³ C-H stretch), 1685 (C=O stretch), 1512, 1435 (*sp*² C=C stretch), 1288, 1244 (*sp*³ C-O stretch), 832, 771 (*sp*² C-H oop bending). m.p = 36-38 °C

Synthesis of (R)-2-(1-(4-methoxyphenyl)hex-5-en-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (6): To a solution of primary carbamate (2 g, 6.82 mmol, 1.0 eq) (4) and (-) sparteine

(1.88 mL, 8.18 mmol, 1.2 eq.) (5a) in Et₂O (34 mL) at -78 °C was added *sec*-BuLi (1.6 M in 92:8 cyclohexane/hexane, 5.8 mL, 7.50 mmol, 1.1 eq.) dropwise. The resulting mixture was stirred for 5 h at -78 °C before allylboronic acid pinacol ester (1.53 mL, 8.18 mmol, 1.2 eq.) (5) was dropwise added. The reaction mixture was further stirred at -78 °C for 1 h, allowed to warm to room temperature. A solution of MgBr₂·OEt₂ in Et₂O, made as follows, was added to the reaction mixture at this point: [1,2-dibromoethane (1.19 mL, 13.77 mmol, 1.0 eq) was added to a suspension of magnesium (0.33 g, 13.77 mmol, 1.0 eq.) in Et₂O (17.2 mL) at room temperature. The reaction flask was then placed into a water bath in order to control the moderate exotherm and was further stirred for 2 h. Both layers of the biphasic mixture thus obtained were transferred to the former mixture *via* syringe. The mixture was refluxed for 16 h.

The reaction mixture was allowed to cool down to room temperature and was carefully quenched with water. Diethyl ether was added, the layers were separated and the aqueous phase was extracted with Et₂O. The combined organic layers were washed with 1N HCl, 1N NaOH, water and brine, dried MgSO₄, concentrated and purified by column chromatography (SiO₂) to obtain the pure (R)-2-(1-(4-methoxyphenyl)hex-5-en-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (6) (1.67 g, 77.6 %) as colorless oil (Fig. 2).

Complete characterization was done by ¹H NMR, ¹³C NMR and IR. Fine peaks confirmed the purity of the secondary boronic ester (6) and it was used as starting material for reaction (Fig. 4). ¹H NMR (400 MHz, CDCl₃) δ ppm 7.09 (2H, d, *J* = 8.80 Hz, 2 × *ArH*) 6.81 (2H, d, *J* = 8.80 Hz, 2 × *ArH*) 5.86-5.75 (1H, m, CH=CH₂) 5.04 (1H, d, *J* = 2.20 Hz, CH=CHH) 4.94 (1H, d, *J* = 10.27 Hz, CH=CHH) 3.78 (3H, s, OCH₃) 2.63-2.48 (2H, m, ArCH₂CH₂CHBCH₂) 2.27-2.11 (2H, m, ArCH₂CH₂CHBCH₂) 1.78-1.58 (2H, m, ArCH₂CH₂CHBCH₂) 1.25 (12H, s, 4 × CH₃) 1.08-1.18 (1H, m, ArCH₂CH₂CHBCH₂) ¹³C NMR (100 MHz, CDCl₃) δ ppm 157.6 (1C, -OCH₃), 138.4 (2C, 2 × ArCH), 135.0 (2C, 2 × ArCH), 129.2 (1C, ArC-O), 114.9 (1C, -CH₂CH=CH₂), 113.6 (1C, -CH=CH₂), 83.0 (2C, 2 × C(CH₃)₂), 55.2 (1C, ArCCH₂), 35.3 (1C, -CH₂CH₂CHB), 34.5 (1C, -CH₂CHB), 33.1 (1C, -CHBCH₂CH), 24.9 (1C, -CH₂CH₂CHB), 24.8 (4C, 2 × (CH₃)₂C). ¹¹B NMR (96.23 MHz, None) δ ppm 33.24. IR (film): ν(cm⁻¹) 3026 (*sp*² C-H Stretch),

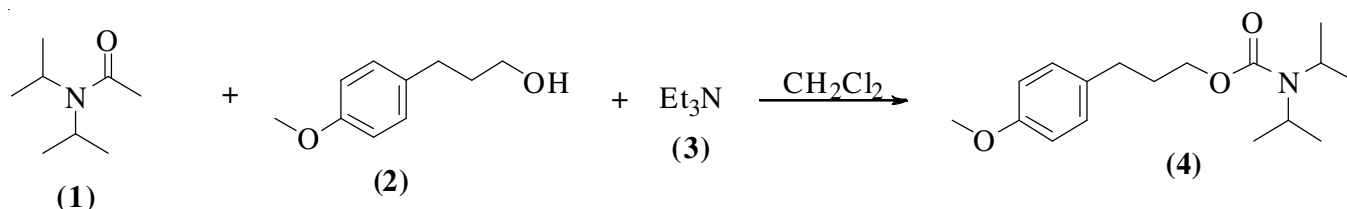


Fig. 1. 3-(4-Methoxyphenyl) propyl-N,N-disopropylcarbamate

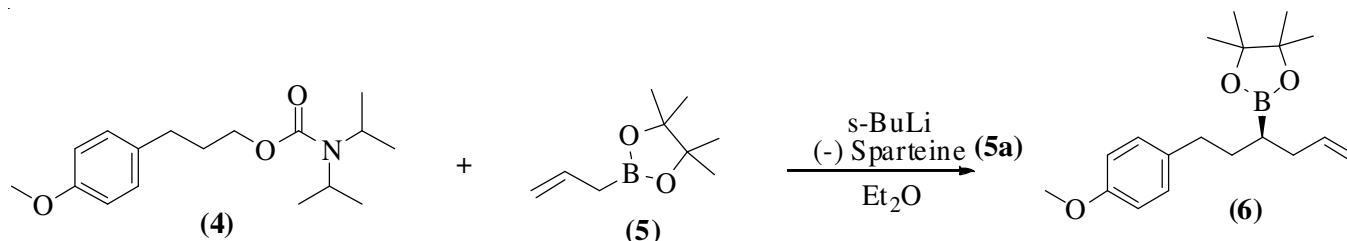


Fig. 2. Synthesis of (R)-2-(1-(4-methoxyphenyl)hex-5-ene-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane

2977, 2924, 2852 (sp^3 C-H stretch), 1511, 1456 (sp^2 C=C stretch), 1243, 1175, 1142 (sp^3 C-O stretch), 846, 822, 670 (sp^2 C-H oop bending).

Synthesis of 2-(1-(4-methoxyphenyl)hex-5-en-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (7): Racemic 2-(1-(4-methoxyphenyl)hex-5-en-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (7) was prepared by substituting (-)-sparteine by N,N,N,N-tetramethylethylenediamine (TMEDA) (1.22 mL, 8.18 mmol, 1.2 eq.) (5b) (Fig. 3).

Pure *sec*-boronic ester (7) was collected as colorless oil (1.62 g, 75.3 %). ^1H NMR (400 MHz, CDCl_3) δ ppm 7.09 (2H, d, $J = 8.80$ Hz, $2 \times \text{ArH}$) 6.81 (2H, d, $J = 8.80$ Hz, $2 \times \text{ArH}$) 5.86-5.75 (1H, m, $\text{CH}=\text{CH}_2$) 5.04 (1H, d, $J = 2.20$ Hz, $\text{CH}=\text{CHH}$) 4.94 (1H, d, $J = 10.27$ Hz, $\text{CH}=\text{CHH}$) 3.78 (3H, s, OCH_3) 2.63-2.48 (2H, m, $\text{ArCH}_2\text{CH}_2\text{CHBCH}_2$) 2.27-2.11 (2H, m, $\text{ArCH}_2\text{CH}_2\text{CHBCH}_2$) 1.78-1.58 (2H, m, $\text{ArCH}_2\text{CH}_2\text{CHBCH}_2$) 1.25 (12H, s, $4 \times \text{CH}_3$) 1.08-1.18 (1H, m, $\text{ArCH}_2\text{CH}_2\text{CHBCH}_2$) ^{13}C NMR (100 MHz, CDCl_3) δ ppm 157.6 (1C, $-\text{OCH}_3$), 138.4 (2C, $2 \times \text{ArCH}$), 135.0 (2C, $2 \times \text{ArCH}$), 129.2 (1C, $\text{ArC}=\text{O}$), 114.9 (1C, $-\text{CH}_2\text{CH}=\text{CH}_2$), 113.6 (1C, $-\text{CH}=\text{CH}_2$), 83.0 (2C, $2 \times \text{C}(\text{CH}_3)_2$), 55.2 (1C, ArCCH_2), 35.3 (1C, $-\text{CH}_2\text{CH}_2\text{CHB}$), 34.5 (1C, $-\text{CH}_2\text{CHB}$), 33.1 (1C, $-\text{CHBCH}_2\text{CH}$), 24.9 (1C, $-\text{CH}_2\text{CH}_2\text{CHB}$), 24.8 (4C, $2 \times (\text{CH}_3)_2\text{C}$). ^{11}B NMR (96.23 MHz, None) δ ppm 33.24. IR (film): $\nu(\text{cm}^{-1})$ 3390 (O-H stretch), 3001 (sp^2 C-H stretch), 2931, 2835 (sp^3 C-H stretch), 1511, 1441 (sp^2 C=C stretch), 1244, 1177, 1036 (sp^3 C-O stretch), 915, 822 (sp^2 C-H oop bending).

Synthesis of 1-(2-((1R,2S)-2-(chloromethyl)cyclopropyl)ethyl)-4-methoxybenzene (9): To a solution of 1,3-bis(trifluoromethyl)-5-bromobenzene (0.08 g, 0.274 mmol, 1.2 eq) (6a) in THF (2.4 mL) at -78°C was added *n*-BuLi (1.6 M in hexane, 0.17 mL, 0.274 mmol, 1.2 eq.) dropwise. The mixture was stirred 1 h at -78°C before a solution of boronic ester (0.072 g, 0.228 mmol, 1.0 eq.) (6) in THF (1.2 mL) was added dropwise. The reaction mixture was stirred for 0.5 h at -78°C and 0.5 h at room temperature to give the boronate complex solution (8). The reaction mixture was cooled to -40°C , a solution of TCCA (0.064 g, 0.274 mmol, 1.2 eq.) (8a) in MeCN (1.2 mL) was then added dropwise over 1 min and the reaction mixture was stirred for 5 min at -40°C . 20 % $\text{Na}_2\text{S}_2\text{O}_3$ (3 mL) was

added at -40°C and the reaction mixture was allowed to warm to room temperature (Fig. 4). EtOAc was added and the layers were separated. The aqueous phase was extracted with EtOAc, the organic layers were combined, washed with brine, dried (MgSO_4), concentrated. The crude mixture was finally purified by column chromatography (SiO_2 , 99:1 Pentane/EtOAc) to give desired 1-(2-((1R,2S)-2-(chloromethyl)cyclopropyl)ethyl)-4-methoxybenzene (9) as colorless oil (0.025 g, 49 %). ^1H NMR (400 MHz, CDCl_3) δ ppm 7.12 (2H, d, $J = 8.31$ Hz, $2 \times \text{ArH}$) 6.83 (2H, d, $J = 8.80$ Hz, $2 \times \text{ArH}$) 3.79 (3H, s, OCH_3) 3.69 (0.7H, dd, $J = 11.25$, 7.09 Hz, major CHHCl) 3.49-3.34 (0.3 H, minor CHHCl , 1H, m, CHHCl) 2.71 (1H, t, $J = 7.83$ Hz, $\text{ArCHHCH}_2\text{CH}$) 2.66 (1H, t, $J = 7.70$ Hz, $\text{ArCHHCH}_2\text{CH}$) 1.81-1.71 (0.7 H, m, major $\text{ArCH}_2\text{CHHCH}$) 1.65-1.43 (0.3H, minor $\text{ArCH}_2\text{CHHCH}$, 1H, m, $\text{ArCH}_2\text{CHHCH}$) 1.33-1.22 (0.7H, m, major $\text{CH}(\text{CH}_2)\text{CHCH}_2\text{Cl}$) 1.06-0.95 (0.3H, minor $\text{CH}(\text{CH}_2)\text{CHCH}_2\text{Cl}$, 0.7H, m, $\text{CH}(\text{CH}_2)\text{CHCH}_2\text{Cl}$) 0.88-0.81 (0.3H, m, $\text{CH}(\text{CHH})\text{CHCH}_2\text{Cl}$) 0.79-0.70 (0.3H, m, $\text{CH}(\text{CH}_2)\text{CHCH}_2\text{Cl}$) 0.54-0.46 (1H, m, $\text{CH}(\text{CHH})\text{CHCH}_2\text{Cl}$) 0.06 (0.7H, q, $J = 5.54$ Hz, $\text{CH}(\text{CHH})\text{CHCH}_2\text{Cl}$). ^{13}C NMR (100 MHz, CDCl_3) δ ppm 157.77 (1C, major, ArC), 157.71 (1C, minor, ArC), 134.25 (1C, major, ArC), 134.21 (1C, minor, ArC), 129.32 (1C, major, ArC), 113.72 (1C, minor, ArC), 113.69 (1C, major, ArC), 55.26 (1C, major, OCH_3), 55.24 (1C, minor, OCH_3), 50.22 (1C, minor, CH_2Cl), 46.65 (1C, major, CH_2Cl), 35.63 (1C, minor, $\text{CH}_2\text{CH}_2\text{CH}(\text{CH}_2)\text{CHCH}_2\text{Cl}$), 35.26 (1C, major, $\text{CH}_2\text{CH}_2\text{CH}(\text{CH}_2)\text{CHCH}_2\text{Cl}$), 34.69 (1C, minor, $\text{CH}_2\text{CH}_2\text{CH}(\text{CH}_2)\text{CHCH}_2\text{Cl}$), 30.54 (1C, major, $\text{CH}_2\text{CH}_2\text{CH}(\text{CH}_2)\text{CHCH}_2\text{Cl}$), 21.34 (1C, minor, $\text{CH}_2\text{CH}_2\text{CH}(\text{CH}_2)\text{CHCH}_2\text{Cl}$), 19.83 (1C, minor, $\text{CH}_2\text{CH}_2\text{CH}(\text{CH}_2)\text{CHCH}_2\text{Cl}$), 18.54 (1C, major, $\text{CH}_2\text{CH}_2\text{CH}(\text{CH}_2)\text{CHCH}_2\text{Cl}$), 17.72 (1C, major, $\text{CH}_2\text{CH}_2\text{CH}(\text{CH}_2)\text{CHCH}_2\text{Cl}$), 12.93 (1C, minor, $\text{CH}_2\text{CH}_2\text{CH}(\text{CH}_2)\text{CHCH}_2\text{Cl}$), 12.11 (1C, major, $\text{CH}_2\text{CH}_2\text{CH}(\text{CH}_2)\text{CHCH}_2\text{Cl}$). IR (film): $\nu(\text{cm}^{-1})$ 3026 (sp^2 C-H stretch), 2977, 2930, 2855, 2835 (sp^3 C-H stretch), 1510, 1455 (sp^2 C=C stretch), 1242, 1176, 1035 (sp^3 C-O stretch), 822, 696, 575 (sp^3 C-Cl stretch). HRMS (ESI) calcd. for $\text{C}_{13}\text{H}_{17}\text{OCl}$ $[\text{M}+\text{H}]^+$ 225.1039, found 225.1039. $[\alpha]_D^{+25} +3.84$ (c 0.52, CDCl_3)

SFC separation conditions: Chiralpak IA column with guard, 5 % *i*PrOH in hexane, flow rate: 2 mL/min, 39.9°C ; *r*R

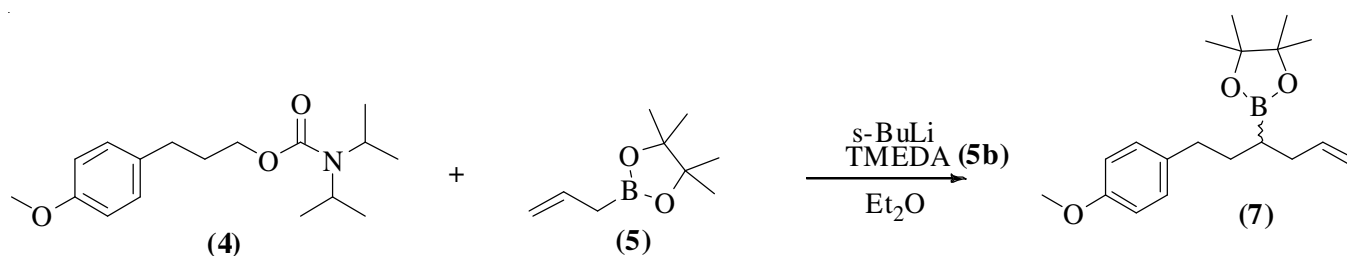


Fig. 3. Synthesis of 2-(1-(4-methoxyphenyl)hex-5-ene-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane

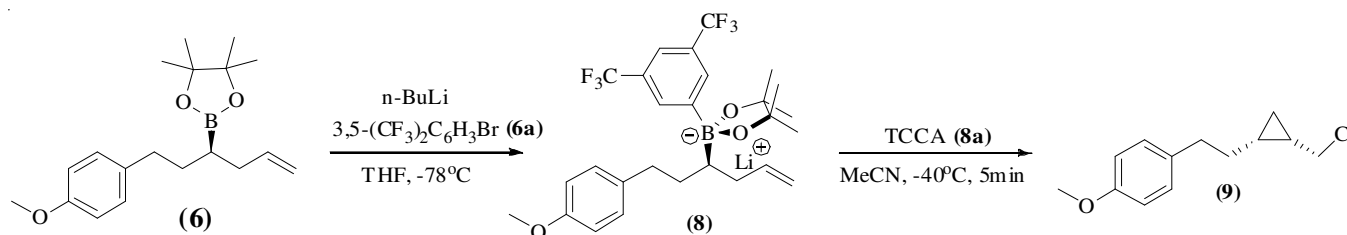


Fig. 4. Synthesis of 1-(2-((1R,2S)-2-(chloromethyl)cyclopropyl)ethyl)-4-methoxybenzene

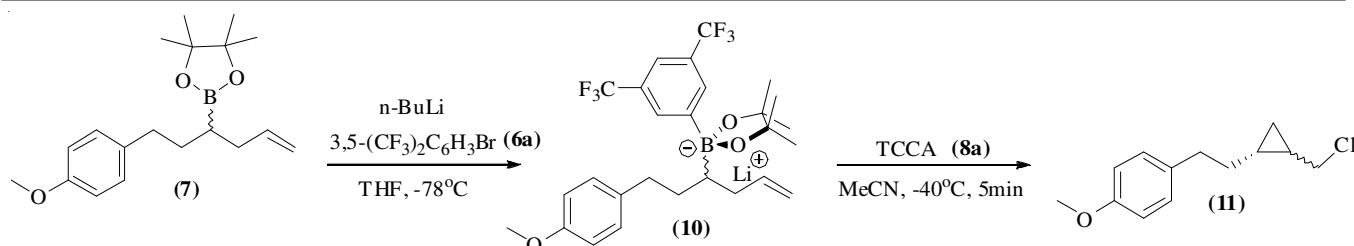


Fig. 5. Synthesis of 1-(2-((1R)-2-(chloromethyl)cyclopropyl)ethyl)-4-methoxybenzene

16.5 min for (R)-enantiomer (minor) and *t*R 23.0 min for (S)-enantiomer (major). e.r. = 68.6:28.9.

Synthesis of 1-(2-((1R)-2-(chloromethyl)cyclopropyl)ethyl)-4-methoxybenzene (11): Product 1-(2-((1R)-2-(chloromethyl)cyclopropyl)ethyl)-4-methoxybenzene (**11**) was synthesized by substituting starting material (**6**) with racemic boronic ester (**7**) (Fig. 5).

Pure product (**11**) was obtained as colorless oil (0.024, 48.6 %). ¹H NMR (400 MHz, CDCl₃) δ ppm 7.12 (2H, d, *J* = 8.31 Hz, 2 × ArH) 6.83 (2H, d, *J* = 8.80 Hz, 2 × ArH) 3.79 (3H, s, OCH₃) 3.69 (0.7H, dd, *J* = 11.25, 7.09 Hz, major CHHCl) 3.49-3.34 (0.3H, minor CHHCl, 1H, m, CHHCl) 2.71 (1H, t, *J* = 7.83 Hz, ArCHHCH₂CH) 2.66 (1H, t, *J* = 7.70 Hz, ArCHHCH₂CH) 1.81-1.71 (0.7H, m, major ArCH₂CHHCH) 1.65-1.43 (0.3H, minor ArCH₂CHHCH, 1H, m, ArCH₂CHHCH) 1.33-1.22 (0.7H, m, major CH(CH₂)CHCH₂Cl) 1.06-0.95 (0.3H, minor CH(CH₂)CHCH₂Cl, 0.7H, m, CH(CH₂)CHCH₂Cl) 0.88-0.81 (0.3H, m, CH(CHH)CHCH₂Cl) 0.79-0.70 (0.3H, m, CH(CH₂)CHCH₂Cl) 0.54-0.46 (1H, m, CH(CHH)CHCH₂Cl) 0.06 (0.7H, q, *J* = 5.54 Hz, CH(CHH)CHCH₂Cl).

¹³C NMR (100 MHz, CDCl₃) δ ppm 157.77 (1C, major, ArC), 157.71 (1C, minor, ArC), 134.25 (1C, major, ArC), 134.21 (1C, minor, ArC), 129.32 (1C, major, ArC), 113.72 (1C, minor, ArC), 113.69 (1C, major, ArC), 55.26 (1C, major, OCH₃), 55.24 (1C, minor, OCH₃), 50.22 (1C, minor, CH₂Cl), 46.65 (1C, major, CH₂Cl), 35.63 (1C, minor, CH₂CH₂CH(CH₂)CHCH₂Cl), 35.26 (1C, major, CH₂CH₂CH(CH₂)CHCH₂Cl), 34.69 (1C, minor, CH₂CH₂CH(CH₂)CHCH₂Cl), 30.54 (1C, major, CH₂CH₂CH(CH₂)CHCH₂Cl), 21.34 (1C, minor, CH₂CH₂CH(CH₂)CHCH₂Cl), 19.83 (1C, minor, CH₂CH₂CH(CH₂)CHCH₂Cl), 18.54 (1C, major, CH₂CH₂CH(CH₂)CHCH₂Cl), 17.72 (1C, major, CH₂CH₂CH(CH₂)CHCH₂Cl), 12.93 (1C, minor, CH₂CH₂CH(CH₂)CHCH₂Cl), 12.11 (1C, major, CH₂CH₂CH(CH₂)CHCH₂Cl). IR (film): ν(cm⁻¹) 3026 (*sp*² C-H stretch), 2977, 2930, 2855, 2835 (*sp*³ C-H stretch), 1510, 1455 (*sp*² C=C stretch), 1242, 1176, 1035 (*sp*³ C-O stretch), 822, 696, 575 (*sp*³ C-Cl stretch). HRMS (ESI) calcd. for C₁₃H₁₇OCl [M+H]⁺ 225.1039, found 225.1039.

SFC separation conditions: Chiralpak IA column with guard, 5% *i*PrOH in hexane, flow rate: 2 mL/min, 39.9 °C; *t*R 16.5 min for (R)-enantiomer (minor) and *t*R 23.0 min for (S)-enantiomer (major).

Synthesis of (R)-1-(4-methoxyphenyl)hex-5-en-3-ol (12)

Oxidation of (R)-2-(1-(4-methoxyphenyl)hex-5-en-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (6): A solution of 3M NaOH/30 % H₂O₂ (2:1 v/v, 1 mL) was added dropwise to a solution of ((R)-2-(1-(4-methoxyphenyl)hex-5-en-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**6**) (0.03 g, 0.115

mmol) in THF/Et₂O (1:1 v/v, 1mL) at 0 °C under vigorous stirring. The reaction mixture was allowed to warm to room temperature and further stirred for 2 h. Et₂O and water was added and phases were separated. The aqueous phase was extracted with Et₂O; the combined organic layers were washed with brine, dried (MgSO₄), concentrated and purified by column chromatography (SiO₂) to obtain the pure (R)-1-(4-methoxyphenyl)hex-5-en-3-ol (**12**) as colourless oil (0.022 g, 73.3 %) (Fig. 6).

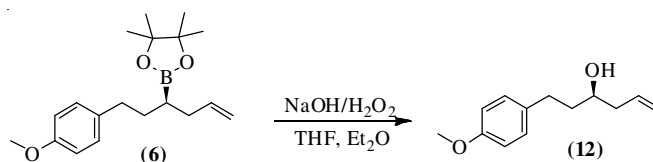


Fig. 6. Synthesis of (R)-1-(4-methoxyphenyl)hex-5-en-3-ol

¹H NMR (400 MHz, CDCl₃) δ ppm 7.12 (2H, d, *J* = 8.80 Hz, 2 × ArH) 6.83 (2H, d, *J* = 8.56 Hz, 2 × ArH) 5.82 (1H, dddd, *J* = 17.64, 9.63, 7.95, 6.60 Hz, CH=CH₂) 5.17-5.14 (1H, m, CH=CHH) 5.14-5.11 (1H, m, CH=CHH) 3.79 (3H, s, OCH₃) 3.66 (1H, br s, -OH) 2.80-2.70 (1H, m, ArCHHCH₂CHBCH₂) 2.68-2.59 (1H, m, ArCHHCH₂CHBCH₂) 2.36-2.27 (1H, m, ArCH₂CH₂CHBCHH) 2.23-2.12 (1H, m, ArCH₂CH₂CHBCHH) 1.79-1.72 (2H, m, ArCH₂CH₂CHBCH₂) 1.60 (1H, br s, ArCH₂CH₂CHBCH₂) ¹³C NMR (100 MHz, CDCl₃) δ ppm 157.7 (1C, -OCH₃), 134.6 (2C, 2 × ArCH), 134.0 (2C, 2 × ArCH), 129.2 (1C, ArC-O), 118.2 (1C, -CH₂CH=CH₂), 113.8 (1C, -CH=CH₂), 69.8 (1C, -CH₂CHB), 55.2 (1C, ArCCH₂), 42.0 (1C, -CHBCH₂CH), 38.6 (1C, -CH₂CH₂CHB), 31.0 (1C, -CH₂CH₂CHB). IR (film): ν (cm⁻¹) 3026 (*sp*² C-H stretch), 2977, 2924, 2852 (*sp*³ C-H stretch), 1511, 1456 (*sp*² C=C stretch), 1243, 1175, 1142 (*sp*³ C-O stretch), 846, 822, 670 (*sp*² C-H oop bending).

SFC separation conditions: Chiralpak IA column with guard, 5 % *i*PrOH in hexane, flow rate: 2 mL/min, 39.9 °C; *t*R 11.4 min for (S)-enantiomer (minor) and *t*R 13.2 min for (R)-enantiomer (major). [α]_D 20 +0.20 (c 1.0, CHCl₃), e.r. = 99.0:1.0. The proposed mechanism are shown in Fig. 7.

RESULTS AND DISCUSSION

3-(4-Methoxyphenyl)propyl-N,N-diisopropylcarbamate (**4**) (Table-1, entry 1) was synthesized in excellent yields by reacting N,N-diisopropylacetamide (**1**) and 3-(4-methoxyphenyl)propan-1-ol (**2**) at mentioned conditions. Both chiral (**6**) and racemic (**7**) secondary boronic esters were prepared by lithiation-borylation reaction in good yields. (R)-2-(1-(4-methoxyphenyl)hex-5-en-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**6**) (Table-1, entry 2) was formed by reacting

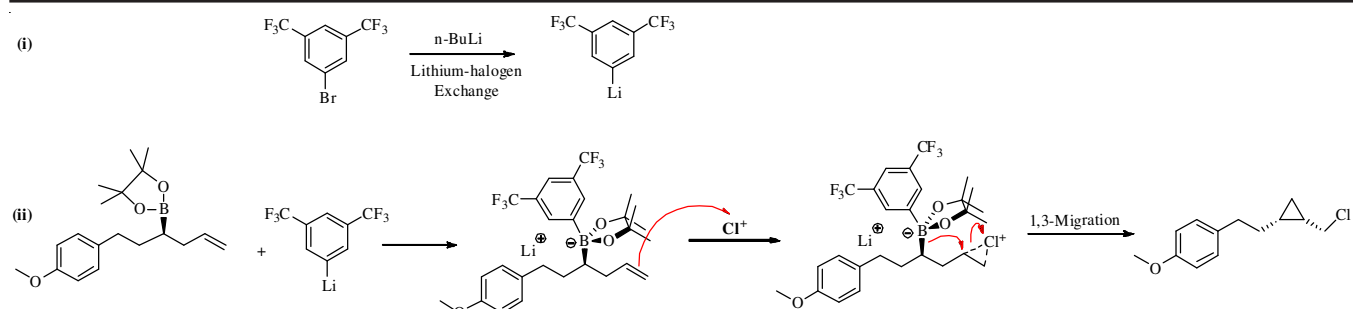


Fig. 7

3-(4-methoxyphenyl)propyl-N,N-diisopropylcarbamate (**4**) with 2-allyl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**5**) in the presence of *sec*-BuLi and (-) sparteine (**5a**) in Et₂O while in the synthesis of 2-(1-(4-methoxyphenyl)hex-5-en-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**7**) (Table-1, entry 3), TMDA (**5b**) was used instead of (-) sparteine (**5a**). These boronic esters (**6**, **7**) were used in cyclopropanation reaction as starting materials.

Boronate complex (**8**) was then synthesized after reacting (R)-2-(1-(4-methoxyphenyl)hex-5-en-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**6**) with 1,3-bis(trifluoromethyl)-5-bromobenzene (**6a**). Boron-ate (**8**) acted as nucleophile and was then combined with some electrophiles like TCCA and NCS, after 1,3-migration it resulted in 1-[2-[(1R,2S)-2-(chloromethyl)cyclopropyl]ethyl]-4-methoxybenzene (**9**). In the same way, boronic ester (**7**) was used to prepare 1-(2-((1R)-2-(chloromethyl)cyclopropyl)ethyl)-4-methoxybenzene

(**11**) through boronate complex (**10**). Both chiral and racemic cyclopropanation products (**9**, **11**) were synthesized and tuned the reaction for best yields and stereoselectivity.

In order to get best yields and stereoselectivity, reaction (Figs. 4 and 5) was investigated at different temperatures using a number of aryllithiums and electrophiles like TCCA and NCS.

Effect of temperature on the reaction was studied first by reacting boronate complex at different temperatures using TCCA as the electrophilic chlorine source. It was found that at higher temperature (room temperature), both yields and d.r. was worse and favoured the other diastereomer (Table-2, entry 1). So reaction was attempted at lower temperatures -40 °C and -78 °C respectively and found that d.r. was only slightly better. At -40 °C, improvement was seen both in yields and d.r. (Table-2, entry 2) so reaction was carried out at further low temperature -78 °C but results were discouraging (Table-2, entry 3).

TABLE-1
PHYSICAL CHARACTERISTIC OF STARTING MATERIALS

Entry	Starting Material	Colour	Yield (%)
1	3-(4-Methoxyphenyl)propyl-N,N-diisopropylcarbamate	White solid	99.0
2	(R)-2-(1-(4-methoxyphenyl) hex-5-en-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane	Colorless oil	77.6
3	2-(1-(4-methoxyphenyl)hex-5-en-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane	Colorless oil	75.3

TABLE-2
EFFECT OF TEMPERATURE ON STEREOSELECTIVITY

Entry	Boronic Ester	Aryllithium	Electrophile	Temp. (°C)	Product	Yield (%)	d.r (%)
1		3,5-(CF ₃) ₂ C ₆ H ₃ Br	TCCA	R.T		13	1.18:1
2		3,5-(CF ₃) ₂ C ₆ H ₃ Br	TCCA	-40		49	2:1
3		3,5-(CF ₃) ₂ C ₆ H ₃ Br	TCCA	-78		22	2.1:1

TABLE-3
EFFECT OF ARYL LITHIUMS ON STEREOSELECTIVITY

Entry	Boronic Ester	Aryllithium	Electrophile	Temp. (°C)	Product	Yield (%)	d.r (%)
1		3,5-(CF ₃) ₂ C ₆ H ₃ Br	TCCA	-40		49	2:1
2		1-Bromonaphthalene	TCCA	-40		67	1.8:1

TABLE-4
 EFFECT OF ELECTROPHILES ON STEREOSELECTIVITY

Entry	Boronic Ester	Aryllithium	Electrophile	Temp. (°C)	Product	Yield (%)	d.r (%)
1		3,5-(CF ₃) ₂ C ₆ H ₃ Br	TCCA	-40		49	12:1
2		3,5-(CF ₃) ₂ C ₆ H ₃ Br	NCS	-40		18	1.8:1

 TABLE-5
 DATA SHOWING STEREOSELECTIVITY AND [α]_D

Entry	Products	d.r	e.r	e.e	e.s	[α] _D
1		2.1:1	68.6:28.9	39.7	0.41	+3.84
2		----	99.0:1.0	98.0	----	+0.20

Then, we investigated if steric bulk of aryl lithium had some affect on stereoselectivity so 3,5-(CF₃)₂C₆H₃Br was replaced by 1-bromonaphthalene at -40 °C. However, the use of 1-bromonaphthalene actually resulted in slightly lower d.r., although yield was slightly improved (Table-3, entry 2).

Similarly, reaction was also tried by changing the electrophiles to see how this would affect the stereoselectivity. In the light of above observations, 3,5-(CF₃)₂C₆H₃Br was used as aryl lithium and temperature was kept -40 °C and reaction was tuned by changing electrophile. Use of NCS instead of TCCA resulted in slightly lower yield and lower diastereoselectivity (Table-4, entry 2).

As analyzed from ¹H NMR, cyclopropanation product 1-[2-((1R,2S)-2-(chloromethyl)cyclopropyl)ethyl]-4-methoxybenzene (**9**) was a mixture of 70:30 (major/minor) diastereomers. For the determination of e.r, (R)-2-(1-(4-methoxyphenyl)hex-5-en-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**6**) was oxidized into (R)-1-(4-methoxyphenyl)hex-5-en-3-ol (0.022g, 73.3 %) (**12**). Enantiomeric ratio determined by supercritical fluid chromatography (SFC) was 68.6:28.9 while enantiomeric excess (e.e), enantioselectivity (e.s) and [α]_D calculated were 39.7, 0.41 and +3.84, respectively (Table-5, entry 1).

Conclusion

Novel 1-[2-((1R,2S)-2-(chloromethyl)cyclopropyl)ethyl]-4-methoxybenzene (**9**) was synthesized in good yields (Table-3, entry 2), diastereometric ratios (d.r) and enantiomeric ratios (e.r) (Table-5, entry 1). Temperature had dominant effect on stereoselectivity (Table-2, entry 2). Best yield for this cyclopropanation reaction was 67 % using 1-bromonaphthalene as aryllithium and performing the reaction at -40 °C (Table-3,

entry 2). The best diastereoselectivity obtained was 2.1:1, using 1,3-bis(trifluoromethyl)-5-bromobenzene at -78 °C (Table-2, entry 3). Enantiomeric ratio (e.r), enantiomeric excess (e.e), enantioselectivity (e.s) and [α]_D for 1-[2-((1R,2S)-2-(chloromethyl)cyclopropyl)ethyl]-4-methoxybenzene (**9**) were 68.6:28.9, 39.7, 0.41 and +3.84 respectively (Table-5, entry 1).

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