Axially chiral P-N ligands for the copper catalysed $\beta$-borylation of $\alpha,\beta$-unsaturated esters.


Supporting Information

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   $^1$H, $^{13}$C NMR Spectra for 2c, 6, 7, 8, 9, 10, $(R_a, R)$-17 and $^1$H Spectra $^1$H NMR spectra for the products of the borations of 3a-c and the $^1$H NMR spectra for the acetylated products of 3a-b and the phenoxy acetylated product of 3d.
1. Experimental Procedures

1.1 General Experimental

All reactions were performed under anhydrous conditions and an inert atmosphere of nitrogen in the oven-dried glassware with magnetic stirring. Yields refer to chromatographically and spectroscopically (\(^1\)H NMR) homogenous materials, unless otherwise indicated. Reagents were used as obtained from commercial sources or purified according to the guidelines of Perrin and Armarego.\(^1\) Evaporation in vacuo refers to the removal of volatiles on a Büchi rotary evaporator with an integrated vacuum pump. Flash chromatography was carried out using Merck Kiesegel 60 F254 (230–400 mesh) silica gel following the method of Still et al.\(^2\) Thin-layer chromatography (TLC) was performed on Merck DC-Alufolien plates pre-coated with silica gel 60 F254. They were visualized either by quenching of ultraviolet fluorescence, or by charring with an acidic vanillin soln. (vanillin, H\(_2\)SO\(_4\) and acetic acid in MeOH). The Microanalytical Laboratory, University College Dublin, performed elemental analyses. Electrospray mass spectra were recorded on a Micromass Quattro with electrospray probe. Exact mass ESI mass spectra (HRMS) were measured on a micromass LCT orthogonal time of flight mass spectrometer with leucine enkephalin (Tyr-Gly-Phe-Leu) as an internal lock mass.\(^1\)H NMR spectra were recorded on a 300 MHz Varian-Unity spectrometer, a 400 MHz Varian-Unity spectrometer or a 500 MHz Varian-Unity spectrometer. Chemical shifts are quoted in ppm relative to tetramethylsilane and coupling constants (J) are quoted in Hz and are uncorrected. CDCl\(_3\) was used as the solvent for all NMR spectra unless otherwise stated. 75.4 MHz \(^{13}\)C spectra were recorded on a 300 MHz Varian-Unity spectrometer, 101 MHz \(^{13}\)C spectra on a 400 MHz Varian-Unity spectrometer and 125 \(^{13}\)C spectra on a 500 MHz Varian-Unity spectrometer. Tetramethylsilane was used as the internal standard in all \(^{13}\)C spectra recorded. 121.4 MHz \(^{31}\)P spectra were recorded on a 300 MHz Varian-Unity spectrometer and 162 MHz \(^{31}\)P spectra on a 400 MHz Varian-Unity spectrometer. \(^{31}\)P Chemical shifts are reported relative to 85% aqueous phosphoric acid (0.0 ppm). All

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reaction solvents were distilled before use, unless otherwise indicated. Anhydrous solvents were obtained from a PureSolv-300-3-MD dry solvent dispenser and used without further purification unless otherwise stated. Melting points (mp) are quoted to the nearest 0.5 °C. GC and HPLC analysis was carried out using a Supelco 2-4304 beta-Dex® 120 (30 m x 0.25 mm, 0.25 mm film) and a Chiralcel OD column (0.46 cm I.D. x 25 cm) respectively. Optical rotation values were measured on a Perkin Elmer 241 Polarimeter. [α]D values are given in 10⁻¹ deg cm² g⁻¹.

1.2 Synthesis and resolution of Quinazolinap 2c

**7-chloro-2-isopropylquinazolin-4(3H)-one 5**

To a solution of 2-amino-4-chlorobenzamide 4 (15.0 g, 88 mmol) and pyridine (7.6 g, 97 mmol) in dichloromethane (150 mL) was added isobutyl chloride (10.3 g, 97 mmol) slowly via syringe and stirred for 1 h. The pale yellow solid formed was filtered and taken up in a solution of aqueous NaOH (5 %, 120 mL) and heated at reflux for 30 min. The solution was cooled to room temperature and acidified to pH ~ 3 with HCl (1 M). The solid was filtered and washed with water to yield the title compound as a white fibrous solid (17.4 g, 89 %). Mp = 200 – 201 °C. ¹H NMR (300 MHz, [D₆]-DMSO) δ = 12.27 (br. s, 1H), 8.06 (br. s, 1H), 8.06 (d, J = 8.5 Hz, 1H), 7.65 (d, J = 1.9 Hz, 1H), 2.88 (sep., J = 6.9 Hz, 1H), 1.24 (d, J = 6.9 Hz, 6H) ppm. ¹³C {¹H} NMR (125 MHz, [D₆]-DMSO) δ = 164.0, 162.0, 150.7, 139.6, 128.5, 126.9, 126.8, 120.5, 34.1, 21.0 ppm. IR (KBr): v_max = 3173, 2930, 1669, 1101 cm⁻¹. C₁₁H₁₂N₂O requires: C 59.33, H 4.98, N 12.55. Found: C 59.20, H 4.95, N 12.40. HRMS calcd. for C₁₁H₁₁N₂OCl 222.0560, found 222.0571.
A solution of 7-chloro-2-isopropylquinolin-4(3H)-one (11.4 g, 51 mmol) and N,N-diethylaniline (11.4 g, 76.5 mmol) in benzene (250 mL) was azeotropically dried. To this was added POCl$_3$ (5.2 g, 34 mmol) via syringe and stirred at reflux for 3 h resulting in a deep red solution. The mixture was cooled to room temperature, diluted with ethyl acetate (150 mL) and washed sequentially with water (2 x 150 mL), HCl (1 M, 2 x 150 mL), water (150 mL), brine (150 mL), NaHCO$_3$ (150 mL), water (150 mL) and brine (150 mL). The solution was dried (MgSO$_4$) and volatiles removed in vacuo to give a red solid. This was purified by column chromatography with pentane:ethyl acetate (4:1) to yield the title compound as a low melting solid. (8.4 g, 69 %) $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ = 8.15 (d, $J$ = 8.9, 1H), 8.00 (d, $J$ = 1.7, 1H), 7.6 (dd, $J$ = 8.9, 1.8, 1H), 3.31 (sep., $J$ = 6.9 1H), 1.14 (d, $J$ = 6.9, 6H) ppm. $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ = 172.2, 162.1, 152.0, 140.0, 128.9, 127.5, 127.0, 120.6, 37.2, 21.4 ppm. IR (NaCl): $\nu_{\text{max}}$ = 2969, 1605, 1572, 1468, 1330, 1311 cm$^{-1}$. HRMS calcd. for C$_{11}$H$_{10}$N$_2$Cl$_2$ 240.0221, found 240.0216.
7-chloro-2-isopropyl-4-(2-methoxynaphthalen-1-yl)quinazoline 8

4,7-dichloro-2-isopropylquinazoline (3.0 g, 12.4 mmol) and Pd(PPh₃)₄ (0.43 g, 0.37 mmol) were dissolved in DME (60 mL) to form a yellow solution. To this was added 2-methoxynaphthalen-1-ylboronic acid (2.5 g, 12.4 mmol) and caesium fluoride (3.8 g, 24.8 mmol). The mixture was stirred at 80 °C for 6 h (TLC). After cooling to room temperature, water (40 mL) and dichloromethane (40 mL) were added. The organic layer was separated and extraction was completed with further portions of dichloromethane, dried (MgSO₄) and reduced in vacuo to give a yellow oil which was purified by column chromatography pentane:ethyl acetate (2:1) to give the title compound as a white solid (2.46 g, 55%). M.p. 128.5 – 129 °C. ¹H NMR (500 MHz, CDCl₃) δ = 8.10 (d, = 1.9 Hz, 1H), 8.03 (d, J = 9.1 Hz, 1H), 7.87 (d, J = 7.9 Hz, 1H), 7.42 (d, J = 9.1 Hz, 1H), 7.40-7.37 (m, 1H), 7.34 (~dt, J = 9.1, 1.2 Hz, 1H), 7.31 (d, J = 1.8 Hz, 1H), 7.29 (d, J = 2.1 Hz, 1H), 7.11 (d, J = 8.5, 1H), 3.48 (sept., J = 6.9, 1H), 1.51 (d, J = 2.4, 3H), 1.49 (d, J = 2.5, 3H) ppm. ¹³C NMR (125 MHz, CDCl₃) δ = 172.9, 167.3, 154.9, 151.7, 139.8, 133.2, 131.6, 129.4, 128.6, 128.3, 127.8, 127.8, 127.5, 124.4, 124.2, 122.3, 119.8, 113.6, 56.8, 38.3, 22.2, 21.7 ppm. IR (KBr disc): vmax =3006, 2964, 2921, 1555 and 1275.

HRMS calcd. for C₂₂H₁₉ClN₂O₂ 262.1186, found 262.1201. C₂₂H₁₀ClN₂O requires C 72.82, H 5.28, N 7.72. Found C 72.72, H 5.50, N 7.57. IR (KBr disc): vmax =3006, 2964, 2921, 1555 and 1275.
To a solution of 7-chloro-2-isopropyl-4-(2-methoxynaphthalen-1-yl)quinazoline (2.0 g, 6.4 mmol) was added a solution of BBr$_3$ in dichloromethane (1 M, 12.8 mL). The resulting dark red/black solution was stirred at room temperature for 16 h. HCl (1 M, 30 mL) was added and stirred for 30 min resulting in an orange precipitate. This was filtered and dried thoroughly. A sample (100 mg) of the crude was purified for analysis. Mp = 156 – 157 °C. $^1$H NMR (400 MHz, CDCl$_3$); $\delta$ = 9.91 (br. s, 1H), 8.08 (d, $J$ = 2.1 Hz, 1H), 7.94 (d, $J$ = 8.9 Hz, 1H), 7.85 (d, $J$ = 8.0 Hz, 1H), 7.51 (d, $J$ = 9.0 Hz, 1H), 7.38 – 7.32 (m, 2H), 7.31 – 7.26 (m, 3H), 3.45 (sept, $J$ = 6.9 Hz, 1H), 1.50 (d, $J$ = 6.9 Hz, 3H), 1.50 (d, $J$ = 6.9 Hz, 3H) ppm. $^{13}$C{$^1$H} NMR (101 MHz CDCl$_3$); $\delta$ = 171.3, 165.8, 155.3, 152.6, 140.4, 133.0, 132.3, 129.4, 128.8, 128.5, 127.5, 126.9, 124.8, 123.8, 120.5, 119.2, 113.9, 37.7, 21.9, 21.3 ppm. HRMS calcd for C$_{21}$H$_{17}$ClN$_2$O 348.1029, found 348.1032. IR (NaCl); 2969, 1603, 1346, 1278, 1090 cm$^{-1}$. The remaining crude naphtol was transferred to a suitable round bottom flask and suspended in dry dichloromethane (20 mL). N,N-dimethylaminopyridine (2.3 g, 19.2 mmol) was added to give a dark brown solution. Trifluoromethanesulfonic anhydride (2.0 g, 7.04 mmol) was added over 5 min and stirred for 16 h. The resulting solution was washed with HCl (1 M, 20 mL) and extraction completed with further portions of dichloromethane. The organic layers were combined, dried (MgSO$_4$) and reduced $\textit{in vacuo}$. Purification was by column chromatography with pentane:ethyl acetate (3:1) to yield the title compound as a white solid (2.5 g, 81 % from 8). Mp = 84.5 - 86.5 °C. $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ = 8.14 (dd, $J$=5.39, 3.67 Hz, 1H), 8.02 (d, $J$ = 8.3 Hz, 1H), 7.62-7.59 (m, 2H), 7.46 (ddd, $J$ = 8.2,
6.9, 1.1 Hz, 1H), 7.36 (dd, J = 8.9, 2.0 Hz, 1H), 7.30-7.23 (m, 3H), 3.47 (sept., J = 6.9 Hz, 1H), 1.48 (app. t, J = 7.2 Hz, 6H) ppm. \(^{13}\)C\(^{1}\)H NMR (125 MHz CDCl\(_3\)) \(\delta = 173.0, 163.3, 151.8, 144.7, 140.5, 132.69, 132.5, 132.3, 128.7, 128.6, 128.5, 128.1, 127.8, 127.7, 127.2, 126.1, 121.7, 119.6, 118.2 (q, J = 320 Hz) 38.3, 21.9, 21.7 ppm (one carbon signal obscured). HRMS calcd. for C\(_{22}\)H\(_{17}\)ClN\(_2\)O\(_3\)F\(_3\)S 481.0601, found 481.0595 [M+H]\(^+\). C\(_{22}\)H\(_{16}\)ClF\(_3\)N\(_2\)O\(_3\)S requires C 54.95, H 3.35, N 5.83. Found C 54.90, H 3.51, N 5.66. IR (KBr disc): \(\nu_{\text{max}} = 3057, 2981, 2876, 1606, 1509\) and 1474.

**7-chloro-4-(2-(diphenylphosphino)naphthalen-1-yl)-2-isopropylquinazoline 2c**

![Chemical structure](image)

To a solution of NiCl\(_2\)(dppe) [144 mg, 0.77 mmol; dppe: 1,2-bis(diphenylphosphine)-ethane] in DMF (8 mL) was added Ph\(_2\)PH (780 mg, 4.2 mmol), and the mixture was stirred at 100 °C for 30 min. A solution of triflate 10 (2.7 g, 5.6 mmol) and DABCO (2.5 g, 22.3 mmol) in DMF (8 mL) was added via cannula to give initially a pale green transparent solution which over the course of 1 h became a dark brown solution. After 1 h a second portion of Ph\(_2\)PH (780 mg, 4.2 mmol) was added. After 24 h at 100 °C the solution was cooled to room temperature and filtered through Celite\(^\circledR\) the residue was reduced in vacuo and taken up in dichloromethane and washed with water and brine. The organic layer was dried (MgSO\(_4\)), and concentrated in vacuo to give a brown oil. Flash chromatography (silica gel, pentane/EtOAc 4:1) gave a mixture of the mono- and diphosphenylated products. These were isolated by column chromatography (silica gel, pentane/EtOAc 9:1). The monocoupled product was isolated as a white solid (980 mg, 35 \%) mp 142 – 143 °C. \(^1\)H NMR (600 MHz, CDCl\(_3\)) \(\delta = 8.07 (d, J = 1.8 Hz, 1H), 7.91 (d, J = 8.5 Hz, 1H), 7.90 (d, J = 8.2 Hz, 1H), 7.51 (dt, J = 7.9, 0.8 Hz, 1H), 7.36 (dd, J = 8.6, 3.1 Hz, 1H), 7.32 (dt, J = 8.1, 0.9 Hz, 1H), 7.30 – 7.20 (m, 9H), 7.19 (d, J = 1.9 Hz, 1H),
7.13 (t, J = 6.9 Hz, 2H), 7.07 (d, J = 8.5 Hz, 1H), 3.25 (sept, J = 6.9 Hz, 1H), 1.25 (d, J = 6.9 Hz, 3H), 1.24 (d, J = 6.8 Hz, 3H) ppm. $^{13}$C$\{^1$H$\}$ NMR (125 MHz CDCl$_3$) $\delta$ = 172.4, 169.1 (d, $J_{C-P}$ = 6.7 Hz), 151.2, 141.6 (d, $J_{C-P}$ = 32.6 Hz), 139.6, 137.0 (d, $J_{C-P}$ = 11.8 Hz), 136.4 (d, $J_{C-P}$ = 11.2 Hz), 134.6 (d, $J_{C-P}$ = 15.1 Hz), 133.7 (d, $J_{C-P}$ = 20.2 Hz), 133.5, 133.4 (d, $J_{C-P}$ = 19.1 Hz), 131.8 (d, $J_{C-P}$ = 8.8 Hz), 130.0, 129.3, 127.7, 128.4(d, $J_{C-P}$ = 6.7 Hz), 128.4, 128.3 (d, $J_{C-P}$ = 6.7 Hz), 128.2, 128.1, 127.7, 127.6, 127.1, 126.0, 122.1, 37.9, 21.7, 21.1 ppm. $^{31}$P$\{^1$H$\}$ NMR (121 MHz, CDCl$_3$) $\delta$ = 13.5 ppm.

$^{1}$H NMR (400 MHz, CDCl$_3$): 7.88 (d, J = 7.7, 3H), 7.49 (app t, J = 8.0, 1H), 7.42 – 7.28 (m, 12H), 7.28 – 7.10 (m, 14H), 3.23 (sept, J = 6.9, 3H), 1.25 (d, J = 6.9, 3H) ppm. $^{31}$P$\{^1$H$\}$ NMR (243 MHz, CDCl$_3$) $\delta$ = -3.2, -13.6 ppm. IR (KBr): $\upsilon_{\text{max}}$ = 3048, 2957, 1601, 1555, 1475, 1089 cm$^{-1}$. HRMS calcd. for C$_{33}$H$_{27}$N$_2$ClP 517.1600, found 517.1588 [M+H]$^+$. C$_{45}$H$_{36}$N$_2$P$_2$ requires: C 81.06, H 5.44, N 4.20. Found : C 80.80, H 5.61, N 4.48.

7-chloro-4-(2-(diphenylphosphino)naphthalen-1-yl)-2-isopropylquinazoline resolution complex

1. $\begin{align*}
\text{(R,R)-cis 13} & \\
\text{(±)-2c} & \xrightarrow{\text{MeOH, H$_2$O, KPF$_6$}} \\
\text{2. Fractional crystallisation (butanone/Et$_2$O)}
\end{align*}$

$\begin{align*}
\text{(S$_a$, R)-16} & \\
\text{(R$_a$, R)-17} & \xrightarrow{PF_6} \\
\text{PF}_6
\end{align*}$
(+)-di-µ-chlorobis[(R)-dimethyl(1-(1-naphtyl)ethyl)-aminato-C₂,N]dipalladium(II) (131 mg, 0.2 mmol) and (R,S) 7-chloro-4-(2-(diphenylphosphino)naphthalen-1-yl)-2-isopropylquinazoline (200 mg, 0.4 mmol) were dissolved in MeOH (10 mL) and stirred for 16 h to give a yellow solution. To this was added KPF₆ (74 mg, 0.4 mmol) in water (5 mL) upon which a yellow precipitate formed. Stirring was continued for 10 min and filtered to yield a yellow powder which was shown to be a 1:1 mixture of the (R,R) and (S,R) bidentate complex (³¹P NMR showed two peaks of equal intensity at 33.9 and 40.9 ppm). Crystallisation from butanone/diethyl ether gave a single diastereomer (77 mg, 40 %). Mp 219.5 – 220.0 °C. ¹H NMR (600 MHz, CDCl₃) δ = 8.18 (d, J = 8.7 Hz, 1H), 8.09 (d, J = 8.3 Hz, 1H), 7.85 (d, J = 1.9 Hz, 1H), 7.77 – 7.61 (m, 4H), 7.59 – 7.51 (m, 1H), 7.49 – 7.10 (m, 10H), 7.07 (d, J = 8.5 Hz, 1H), 6.88 (d, J = 9.1 Hz, 2H), 6.77 – 6.60 (m, 4H), 4.36 - 4.24 (m, 2H), 2.70 (d, J = 2.2 Hz, 3H), 2.48 (d, J = 3.4 Hz, 3H), 1.78 (d, J = 6.6, 3H), 1.60 (d, J = 6.6, 3H), 1.30 (d, J = 6.3, 3H) ppm. ¹³C{¹H} NMR (150 MHz CDCl₃) δ = 170.5, 165.3 (d, Jₐₗₚ = 6.2 Hz), 151.5, 150.1, 149.1, 142.8, 136.4 (d, Jₐₗₚ = 12.3 Hz), 136.3 (d, Jₐₗₚ = 12.3 Hz), 135.4 (d, Jₐₗₚ = 11.2 Hz), 134.1, 132.7 (d, Jₐₗₚ = 8.4 Hz), 132.4, 132.1, 132.0 (d, Jₐₗₚ = 8.4 Hz), 131.7, 130.1, 129.8, 129.4, 129.1, 129.0, 128.7 (d, Jₐₗₚ = 5.1 Hz), 127.5, 127.1, 126.8, 126.7, 128.7 (d, Jₐₗₚ = 5.1 Hz), 127.5, 127.1, 126.8, 126.7, 126.3 (d, Jₐₗₚ = 6.2 Hz), 125.3 (d, Jₐₗₚ = 6.2 Hz), 125.1, 125.1, 123.8, 123.5, 123.1, 122.0, 121.3, 73.8, 51.5, 48.3, 38.2, 24.2, 23.2, 22.3 ppm. ³¹P{¹H} NMR (243 MHz, CDCl₃) δ = 33.9 ppm. IR = 2361, 1604, 1565, 842 cm⁻¹. C₄₇H₄₂ClF₆N₃P₂Pd requires: C 58.40, H 4.38, N 4.35. Found C 58.27, H 4.44, N 4.26. [α]⁺²¹D = -199° (c 1, CHCl₃)

Decomplexation of enantiopure 7-chloro-4-(2-(diphenylphosphino)naphthalen-1-yl)-2-isopropylquinazoline (Rₐ)-2c

![Decomplexation Diagram]
The palladium complex (313 mg, 0.4 mmol) was dissolved in dichloromethane (5 mL) and to this was added 1,2-bis(diphenylphosphine)ethane (159 mg, 0.4 mmol) and stirred for 3 h at room temperature. Solvent was removed in vacuo and the resulting solid was purified by column chromatography (CH$_2$Cl$_2$) to give ($R_a$)-7-chloro-4-(2-(diphenylphosphino)naphthalen-1-yl)-2-isopropylquinazoline as a white solid (95 %). $[^2]_{D}^o = +102^\circ$ (c 1, CHCl$_3$). Identical in all other respects to previously prepared racemic sample. The stereochemistry was assigned by X-ray crystallography.

**General procedure for the borylation of α,β-unsaturated esters:** THF (3 mL) was added to CuCl (0.010 mmol, 1 mg), NaOtBu (0.015 mmol, 1.4 mg) and ligand (0.020 mmol) in a dry Schlenk tube under nitrogen. The mixture was stirred for 30 min. at room temperature, at this point bis(pinacolato)diboron (0.550 mmol, 139.7 g) was added and stirred for a further 10 mins. The α,β-unsaturated ester (0.500 mmol) was then added followed by MeOH (1 mmol, 0.040 mL). Stirring was continued for 6 h and a sample removed for $^1$H NMR analysis.

**Oxidation:** To the reaction vessel in which the borylation reaction was carried out was added water (2.5 mL) and sodium perborate monohydrate (2.0 mmol, 0.20 g). The reaction mixture was stirred for 12 h at room temperature at which time a further portion of water (2.5 mL) was added. The product was extracted with ethyl acetate (3 x 15 mL) and the combined organics washed with brine, dried over MgSO$_4$ and volatiles reduced in vacuo to give a clear oil which was used without further purification for the final derivatisation.

**Acylation:** The oxidised product was dissolved in dry dichloromethane (3 mL) in a dry Schlenk and to this was added triethylamine (1 mL), DMAP (6 mg, 0.05 mmol) and acetic anhydride (0.150 mL, 1.6 mmol). The mixture was heated to 50 °C for 1 h. The product was purified by silica gel chromatography to give a colourless oil. Ees were determined using GC analysis.
Preparation of Phenoxy derivative of the product of borylation of \( \tau \)-Butyl crotonate: (for the borylation of \( \tau \)-butyl crotonate, the acylated derivative proved inseparable by GC). The oxidised product was dissolved in THF and to this was added DMAP (19 mg, 0.26 mmol), triethylamine (174 \( \mu \)L, 1.25 mmol) and benzoyl chloride to give a white precipitate. Phenoxy acetic acid (95 mg, 0.625 mmol) was then added and stirred at room temperature for 1 h. The product was purified by silica gel chromatography to yield a colourless oil.

\[
\text{Methyl 3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)butanoate:}
\]

\[
\begin{align*}
\text{Bpin} & \quad \text{O} \\
\text{Me} & \quad \text{O} \\
\end{align*}
\]

The title compound was prepared using the general procedure. \(^1\)H NMR was carried out on the crude reaction mixture following removal of THF \textit{in vacuo}. \(^1\)H NMR (300 MHz, CDCl\(_3\)); \( \delta = 3.58 \) (s, 3 H), 2.38 (dd, \( J = 16.4, 7.7 \) Hz, 1 H), 2.32 (dd, \( J = 16.3, 8.7 \) Hz, 1 H), 1.42-1.22 (m, 1 H), 1.17 (s, 12 H), 0.93 (d, \( J = 7.5 \) ppm).

\[
\text{Ethyl 3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)butanoate:}
\]

\[
\begin{align*}
\text{Bpin} & \quad \text{O} \\
\text{Et} & \quad \text{O} \\
\end{align*}
\]

The title compound was prepared using the general procedure. \(^1\)H NMR was carried out on the crude reaction mixture following removal of THF \textit{in vacuo}. \(^1\)H NMR (300 MHz, CDCl\(_3\)); \( \delta = 4.11 \) (q, \( J = 7.1 \) Hz, 2 H), 2.39 (dd, \( J = 16.3, 7.8 \) Hz, 1 H), 2.36 (dd, \( J = 16.6, 8.6 \) Hz), 1.45-1.30 (m, obs., 1 H), 1.23 (br. s, 15 H), 0.99 (d, \( J = 7.5 \) Hz, 3 H) ppm.

\[
\text{Isobutyl 3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)butanoate:}
\]

\[
\begin{align*}
\text{Bpin} & \quad \text{O} \\
\text{iBu} & \quad \text{O} \\
\end{align*}
\]

The title compound was prepared using the general procedure. \(^1\)H NMR was carried out on the crude reaction mixture following removal of THF \textit{in vacuo}. \(^1\)H NMR (300 MHz, CDCl\(_3\)); \( \delta = 3.77 \) (dd, \( J = 6.5, 3.6 \) Hz, 2 H), 2.35 (dd, \( J = 16.4, 7.6 \) Hz 1 H), 2.32 (dd, \( J = 16.3, 6.9 \) Hz, 1 H), 1.97-1.72 (m, 1 H), 1.42-1.24 (m, 1 H), 1.12 (s, 12 H), 0.93 (d, \( J = 7.5, 3 \) H), 0.85 (d, \( J = 6.7, 6 \) H) ppm.

\[
\text{Tert-butyl 3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)butanoate:}
\]

\[
\begin{align*}
\text{Bpin} & \quad \text{O} \\
tBu & \quad \text{O} \\
\end{align*}
\]

The title compound was prepared using the general procedure. \(^1\)H NMR was carried out on the crude reaction mixture following removal of THF \textit{in vacuo}. \(^1\)H
NMR (300 MHz, CDCl$_3$): $\delta = 2.32$ (dd, $J = 8.7$, 16.6 Hz, 1 H), 2.27 (dd, $J = 7.8$, 16.6 Hz, 1 H), 1.36-1.25 (m, obs., 1 H), 1.25 (s, 12 H), 1.22 (s, 9 H), 0.97 (d, $J = 7.44$, 3 H) ppm.

**Methyl 3-acetoxybutanoate:** Prepared using the general acylation procedure. Ees were determined using chiral GC; $\beta$-CD, 30 m, 80 °C, 11.4 psi, $R_T$ = 17.4 min (R), 19.7 min (S). $^1$H NMR (300 MHz, CDCl$_3$): $\delta = 5.31$-5.18 (m, 1 H), 3.67 (s, 3 H), 2.57 (dd, $J = 15.5$, 7.5 Hz, 1 H), 2.55 (dd, $J = 15.5$, 5.8 Hz, 1 H), 2.01 (s, 3 H), 1.28 (d, $J = 6.3$ Hz, 3 H) ppm.

**Ethyl 3-acetoxybutanoate:** Prepared using the general acylation procedure. Ees were determined using chiral GC; $\beta$-CD, 30 m, 80 °C, 27.1 psi, $R_T$ = 13.8 min (R), 14.5 min (S). $^1$H NMR (300 MHz, CDCl$_3$): $\delta = 5.30$-5.20 (m, 1 H), 3.60 (q, $J = 7.28$, 2 H), 2.57 (dd, $J = 15.4$, 7.4 Hz, 1 H), 2.54 (dd, $J = 15.4$, 8.0 Hz, 1 H), 2.01 (s, 3 H), 1.29 (t, $J = 7.24$ Hz, 3 H), 1.22 (d, $J = 7.4$, 3 H) ppm.

**Butyl 3-acetoxybutanoate:** Prepared using the general acylation procedure. Ees were determined using chiral GC; $\beta$-CD, 30 m, 100 °C, 14.5 psi, $R_T$ = 17.9 min (R), 20.1 min (S). $^1$H NMR (300 MHz, CDCl$_3$): $\delta = 5.31$-5.19 (m, 1 H), 3.85 (d, $J = 6.6$, 2 H), 2.56 (dd, $J = 15.5$, 7.5 Hz, 1 H), 2.54 (dd, $J = 15.5$, 5.6 Hz, 1 H), 1.99 (s, 3 H), 1.95-1.82 (m, 1 H), 1.28 (d, $J = 6.3$ Hz, 3 H), 0.90 (d, $J = 6.7$ Hz, 6 H) ppm.

**Tert-butyl 3-(2-phenoxyacroxy)butanoate:** Prepared as described above. Ees were determined using chiral HPLC, chiralcel OD column, hexane:IPA (85:15), 1 mL/min. 220 nm. $R_T$ = 20.7 (S) min, 31.8 min (R). $^1$H NMR (300 MHz, CDCl$_3$): $\delta = 7.29$ (t, $J = 7.6$ Hz, 2H), 6.99 (t, $J = 7.3$ Hz, 1H), 6.90 (d, $J = 8.1$ Hz, 2H), 5.39 (sext, $J = 6.6$ Hz, 1H), 4.58 (s, 2H), 2.53 (dd, $J = 15.5$, 7.7 Hz, 1H), 2.50 (dd, $J = 15.4$, 7.8 Hz, 1H), 1.44 (s, 9H), 1.32 (d, $J = 6.3$ Hz, 3H) ppm.
Single Crystal X-ray Structure Data

Crystal data and structure refinement for Pd$^{II}$ complex ($S_{m}$ R)-14.

Empirical formula \( \text{C}_{66}\text{H}_{52}\text{N}_{4}\text{P}_{2}\text{Cl}_{4}\text{Cu}_{2} \)
Formula weight 1231.94
Temperature 293(2) K
Wavelength 0.71073 Å
Crystal system Triclinic
Space group P–1 (#2)
Unit cell dimensions \( a = 10.7093(9) \, \text{Å} \), \( \alpha = 114.885(2)^\circ \).
\( b = 12.0684(11) \, \text{Å} \), \( \beta = 100.794(2)^\circ \).
\( c = 13.4541(12) \, \text{Å} \), \( \gamma = 96.372(2)^\circ \).
Volume 1514.0(2) Å$^3$
Z 1
Density (calculated) 1.351 Mg/m$^3$
Absorption coefficient 0.975 mm$^{-1}$
\( F(000) \) 632
Crystal size 0.30 x 0.15 x 0.15 mm$^3$
Theta range for data collection 1.73 to 22.51°.
Index ranges \(-11 \leq h \leq 11, -12 \leq k \leq 12, -14 \leq l \leq 14 \)
Reflections collected 9554
Independent reflections 3953 [R(int) = 0.0228]
Completeness to theta = 99.8 %
22.51°
Absorption correction Semi–empirical from equivalents
Max. and min. transmission 0.8675 and 0.6626
Refinement method Full–matrix least–squares on F$^2$
Data / restraints / parameters 3953 / 0 / 354
Goodness–of–fit on F$^2$ 1.103
Final R indices [I>2sigma(I)] R1 = 0.0535, wR2 = 0.1509
R indices (all data) R1 = 0.0666, wR2 = 0.1572
Largest diff. peak and hole 1.391 and -0.474 e.Å$^{-3}$
Crystal data and structure refinement for CuI complex of 2c.

The quinazoline unit showed signs of disorder in earlier stages of refinement. An attempt to refine this disorder did not lead to a chemically reasonable result, thus it was neglected in the final refinement. The residual electron density close to the isopropyl moiety is due to this unrefineable disorder: it marks the position of the minor occupied chlorine atom.

Empirical formula \( \text{C}_{66} \text{H}_{52} \text{N}_4 \text{P}_2 \text{Cl}_4 \text{Cu}_2 \)

Formula weight 1231.94

Temperature 293(2) K

Wavelength 0.71073 Å

Crystal system Triclinic

Space group P–1 (#2)

Unit cell dimensions
\[ a = 10.7093(9) \text{ Å} \quad \alpha = 114.885(2)°. \]
\[ b = 12.0684(11) \text{ Å} \quad \beta = 100.794(2)°. \]
\[ c = 13.4541(12) \text{ Å} \quad \gamma = 96.372(2)°. \]

Volume 1514.0(2) Å³

Z 1

Density (calculated) 1.351 Mg/m³

Absorption coefficient 0.975 mm⁻¹

F(000) 632

Crystal size 0.30 x 0.15 x 0.15 mm³

Theta range for data collection 1.73 to 22.51°.

Index ranges \(-11 \leq h \leq 11, -12 \leq k \leq 12, -14 \leq l \leq 14\)

Reflections collected 9554

Independent reflections 3953 \([R(\text{int}) = 0.0228]\)

Completeness to theta = 99.8 %

Absorption correction Semi–empirical from equivalents

Max. and min. transmission 0.8675 and 0.6626

Refinement method Full–matrix least–squares on \( F^2 \)

Data / restraints / parameters 3953 / 0 / 354

Goodness–of–fit on \( F^2 \) 1.103

Final R indices \([I>2\sigma(I)]\) \( R1 = 0.0535, \ wR2 = 0.1509 \)

R indices (all data) \( R1 = 0.0666, \ wR2 = 0.1572 \)

Largest diff. peak and hole 1.391 and –0.474 e.Å⁻³
HPLC and GC Traces

Shimadzu CLASS-VP V6.10  
Method Name: C:\CLASS-VP\Brian\Ev1\met
Data Name: C:\CLASS-VP\Billy\MA347-40003
User: System
Acquired: 20/10/2008 15:52:41
Printed: 23/10/2008 14:48:12

1. Racemic

Detector A (220nm)

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Data Name: C:\CLASS-VP\Billy\BF Cat 89\001
User: System
Acquired: 23/10/2008 16:28:22
Printed: 28/10/2008 10:37:24

72 % ee

Detector A (220nm)

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Totals: 28351012  100.000  704234  100.000
Racemic

72 % ee
Start 15.0 mins...

Quinap 79%
Qualitative Analysis Report

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Sample Name: BF 1.20 B (16)
Sample Type: Unavailable
Instrument Name: Unavailable
Acq Method: Unavailable
DA Method: Proces_formula.m

Position: Unavailable
User Name: Unavailable
IRM Calibration Status: Unavailable
Comment: -

User Chromatograms

Fragmentor Voltage: 150
Collision Energy: 0
Ionization Mode: ESI

Counts vs. Acquisition Time (min)

Integration Peak List

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50 % ee
Product of boration of 3a
Product of boration of 3b
Product of boration of 3c
Product of boration of 3d

Supplementary Material (ESI) for Organic & Biomolecular Chemistry
This journal is (c) The Royal Society of Chemistry 2009
Product of acylation of 3a
Product of acylation of 3b
Product of Phenoxy acylation of 3c