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A highly effective azetidine–Pd(II) catalyst for Suzuki–Miyaura coupling reactions in water

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ABSTRACT

Readily-synthesised, water-stable Pd(II) complexes of azetidine-based tridentate ligands have been studied as catalysts for the Suzuki–Miyaura coupling reaction. They are highly active for the coupling of aryl bromides with aryl boronates and also effective for the coupling of aryl chlorides.

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1. Introduction

The palladium-catalysed Suzuki–Miyaura cross-coupling reaction of aryl halides with arylboronic acids is one of the most valuable methods for the synthesis of biaryl derivatives developed over the past decades.[1] The traditional Suzuki–Miyaura reaction usually employs palladium–phosphine complex catalysts.[2–5] However, many of these complexes are sensitive to both air and moisture, and inert-atmosphere techniques are generally required for their efficient manipulation and use. Moreover, their cost and toxicity limit any large-scale industrial applications.[6] Hence, the development of efficient, phosphine-free catalysts is of current interest. Water-solubility is another desirable characteristic for real applications due to the facts that water is cheap, readily available, nonflammable and nontoxic.[7] The problem of low substrate solubility in water can certainly be overcome to some extent by the use of phase-transfer catalysts and mixed-aqueous solvent systems.[8] Recently, non-phosphine Suzuki reaction catalysts involving ligands such as *N*-heterocyclic carbenes,[9] some forming palladacycle species,[10] have been reported to be active in mixed-aqueous solvents.[10a,11,12] However, the activity of these systems remains too low to be industrially viable. Herein we report the preparation of palladium complexes containing the tridentate azetidine ligand, **L1**, and some of its derivatives (Fig. 1), which are thermally stable, insensitive to oxygen and moisture and, which have proved to be highly active catalysts for Suzuki–Miyaura reactions.

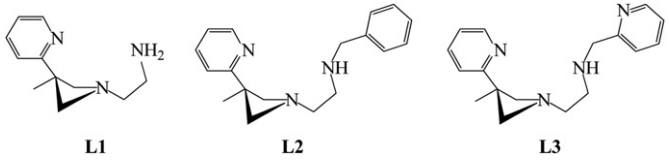

Figure 1. The ligand 1-(2-aminoethyl)-3-methyl-3-(2-pyridyl)azetidine, **L1**, and its derivatives discussed herein.

2. Experimental

2.1. Materials and equipment

All chemicals were purchased from Aldrich and used as-received. NMR spectra were recorded in CD_3OD on Varian Unity Inova 400 (400.265 MHz) or Varian Gemini 2000 (199.976 MHz) instruments. Elemental analysis was carried out with a Chemtronics TEA-3000 instrument.

2.2. Syntheses

The ligand 1-(2-aminoethyl)-3-methyl-3-(2-pyridyl)azetidine, **L1**, was obtained by reaction of the bis(benzenesulfonate) of 2-methyl-2(2-pyridyl)propan-1,3-diol with 1,2-ethanediamine, as described elsewhere.[13]

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*2.2.1. 1-(2-Benzylaminoethyl)-3-methyl-3-(2-pyridyl)azetidine, **L2***

Ligand **L1** (0.5 g, 2.6 mmol) and benzaldehyde (0.28 g, 2.6 mmol) were dissolved in absolute ethanol (100 mL) and heated at 60 °C under nitrogen for 24 h. The solvent was removed under vacuum and the residue redissolved in methanol (100 mL) before $NaBH_4$ (0.2 g, 5.2 mmol) was added and the mixture stirred for 12 h at room temperature. HCl (2 mol L^{-1}, 10 mL) was added to destroy any excess borohydride, then the solvent was removed under vacuum. The residue was dissolved in NaOH (2 mol L^{-1}, 50 mL) and the solution extracted with CH_2Cl_2 (3×50 mL). The combined extracts were washed with water (3×50 mL), dried over Na_2SO_4 and the solvent evaporated off to yield a colourless residue (0.7 g) of **L2** used directly in the preparation of its Pd(II) complex **2**. Purification of the ligand itself was most readily conducted by formation and crystallisation of its Cu(II) complex, followed by treatment with HCl to isolate the ligand hydrochloride as a deliquescent, white solid. ^{1}H NMR (400 MHz) in 1 M DCl/D_2O: δ 8.50 (d, 1H, J=4.8 Hz), 8.11 (t, 1H, J_{app}=7.9 Hz), 7.74 (t, 1H, J_{app}=7.9 Hz), 7.56 (t, 1H, J_{app}=6.4 Hz), 7.35, 7.33 (overlapping m, 6H), 3.85 (s, 2H, benzyl CH_2), 3.69, 3.49 (dd, J_{AB}=13 Hz, 4H, azetidine CH_2), 3.45 (br, 4H, ethylene), 1.55 (s, 3H, methyl).

*2.2.2. 1-{2-(2-Pyridylmethylamino)ethyl}-3-methyl-3-(2-pyridyl)-azetidine, **L3***

Ligand **L1** (0.6 g, 3.1 mmol) and pyridine-2-carboxaldehyde (0.35 g, 3.2 mmol) were reacted together following an identical procedure to the above to give 0.81 g of crude ligand (an oil), again used directly for preparation of the Pd(II) complex **3**. Again, the ligand itself was most conveniently purified through formation of its Cu(II) complex. Here, the NMR spectrum was recorded on the free base ligand after extraction from its basic aqueous solution with $CHCl_3$. ^{1}H NMR (400 MHz) in $CDCl_3$: δ 8.44 (unresolved m, 2H), 7.57 (t, 2H, J_{app}=7.9 Hz), 7.27 (d, 1H, J=5 Hz), 7.08 (m, 3H), 7.35, 7.33 (overlapping m, 6H), 3.85 (s, 2H, benzyl CH_2), 3.52, 3.41 (dd, J_{AB}=7 Hz, 4H, azetidine CH_2), 2.61 (br, 4H, ethylene), 1.60 (s, 3H, methyl).

*2.2.3. Chloro{1-(2-aminoethyl)-3-methyl-3-(2-pyridyl)-azetidine}palladium(II) trifluoromethanesulfonate, [Pd(**L1**)Cl]CF_3SO_3, **1***

A mixture of ligand **L1** (0.30 g, 1.6 mmol) and $PdCl_2$ (0.30 g, 1.7 mmol) in methanol (100 mL) was heated at reflux for 24 h under nitrogen. Undissolved $PdCl_2$ was filtered off and the filtrate taken to dryness under vacuum to give a yellow-brown, hygroscopic solid (0.51 g). This was dissolved in methanol (50 mL) containing excess $LiCF_3SO_3$ and the solution allowed to slowly evaporate to give yellow crystals of **1**, [Pd(**L1**)Cl]CF_3SO_3. Anal. Calcd for $C_{12}H_{17}ClF_3N_3O_3PdS$: C, 29.89; H, 3.55; N, 8.71. Found: C, 29.7; H, 3.5; N, 8.8%. ^{1}H NMR (400 MHz in CD_3OD) δ 9.53 (d, J=8.0 Hz, 1H), 8.14 (t, J=8.0 Hz, 1H), 7.81 (d, J=8.0 Hz, 1H), 7.51 (t, J=8 Hz, 1H), 5.31 (br, 2H), 4.41 (d, J=10.0 Hz, 2H), 3.86 (d, J=10.0 Hz, 2H), 3.03 (t, J=6.0 Hz, 2H), 2.83 (m, 2H), 1.83 (s, 3H) ppm. ^{13}C NMR (100 MHz in CD_3OD) δ 164.7, 155.1, 141.7, 125.1, 124.9, 71.66, 64.71, 46.54, 43.14, 22.30 ppm.

*2.2.4. Chloro{1-(2-benzylaminoethyl)-3-methyl-3-(2-pyridyl)-azetidine}palladium(II) perchlorate, [Pd(**L2**)Cl]ClO_4, **2***

A mixture of crude ligand **L2** (0.70 g, 2.5 mmol) and $PdCl_2$ (0.50 g, 2.8 mmol) in methanol (100 mL) was heated at reflux for 24 h under nitrogen. Undissolved $PdCl_2$ was filtered off and the filtrate taken to dryness under vacuum to give a yellow, hygroscopic solid (0.80 g). This was dissolved in methanol (50 mL) and mixed with methanolic $NaClO_4$ to provide yellow crystals of **2**, [Pd(**L2**)Cl]ClO_4. Anal. Calcd for $C_{18}H_{23}Cl_2N_3O_4Pd$: C, 41.36; H, 4.44; N, 8.04. Found: C, 40.9; H, 4.5; N, 8.1%. ^{1}H NMR (400 MHz in CD_3OD) δ 9.64 (d, J=7.2 Hz, 1H), 8.14 (t, J=8.0 Hz, 1H), 7.79 (d, J=8.0 Hz, 1H), 7.62 (d, J=8.8 Hz, 2H), 7.52 (t, J=6.4 Hz, 1H), 7.46 (m, 3H), 4.60 (q, 1H), 4.38 (d, J=13.6 Hz, 1H), 4.23 (d, J=13.6 Hz, 1H), 4.04 (q, 1H), 3.78 (d, J=9.2 Hz, 1H), 3.64 (d, J=9.2 Hz, 1H), 3.11 (m, 1H), 2.87 (m, 2H), 2.56 (m, 1H), 1.78 (s, 3H) ppm; ^{13}C NMR (100 MHz in CD_3OD) δ 164.7, 155.7, 141.8, 136.1, 131.3, 130.3, 130.2, 125.1, 125.0, 72.31, 71.01, 62.30, 56.40, 51.02, 42.97, 22.21 ppm.

*2.2.5. Chloro{1-{2-(2-pyridylmethylamino)ethyl}-3-methyl-3-(2-pyridyl)azetidine}palladium(II) perchlorate, [Pd(**L3**)Cl]ClO_4, **3***

Substituting ligand **L3** for **L2**, the procedure above was repeated to provide yellow crystals of **3**, [Pd(**L3**)Cl]ClO_4. ^{1}H NMR (400 MHz in CD_3OD) δ 8.61 (d, J=8.0 Hz, 1H), 8.17 (t, J=8.0 Hz, 1H), 7.86 (d, J=8.0 Hz, 1H), 7.70 (d, J=8.0 Hz, 2H), 7.64 (t, J=6.0 Hz, 1H), 7.48 (m, 2H), 5.00 (q, 1H), 4.46 (m, 2H), 4.19 (d, J=15.2 Hz, 1H), 3.56 (d, J=15.2 Hz, 1H), 3.44 (m, 2H), 3.10 (m, 2H), 2.95 (m, 1H), 1.77 (s, 3H) ppm. ^{13}C NMR (100 MHz in CD_3OD) δ 164.8, 155.9, 154.0, 141.9, 139.9, 137.3, 132.3, 131.2, 127.1, 127.0, 73.41, 72.83, 62.30, 56.92, 52.14, 44.07, 22.90 ppm.

2.3. Crystallography

The data for compound **1** were collected on a Nonius Kappa-CCD area detector diffractometer[14] using graphite-monochromated Mo Kα radiation (λ=0.71073 Å). The crystal was introduced in a glass capillary with a protecting 'Paratone-N' oil (Hampton Research) coating. The unit cell parameters were determined from 10 frames, then refined on all data. The data (φ- and ω-scan) were processed with HKL2000.[15] The structure was solved by direct methods with SHELXS-97 and subsequent Fourier-difference synthesis and refined by full-matrix least-squares on F^2 with SHELXL-97.[16] Absorption effects were corrected empirically with the program SCALEPACK.[15] All non-hydrogen atoms were refined with anisotropic displacement parameters. The hydrogen atoms bound to N3 were found on a Fourier-difference map and all the others were introduced at calculated positions; all were treated as riding atoms with a displacement parameter equal to 1.2 (NH, CH, CH_2) or 1.5 (CH_3) times that of the parent atom.

X-ray diffraction data for compound **2** were collected at 294(1) K using an ADSC Quantum210 detector at Beamline 4A MXW at The Pohang Light Source. Crystal evaluation and data collection were done using λ=0.76999 Å radiation with a detector-to-crystal distance of 6.0 cm. Preliminary cell constants and an orientation matrix were determined from 36 sets of frames collected at scan intervals of 5° with an exposure time of 1 s per frame. The basic scale file was prepared using the program HKL2000.[15] The reflections were successfully indexed by the automated indexing routine of the DENZO program.[14] The 8750 reflections (see Table 1) were harvested by collecting 72 sets of frames with 5° scans and an exposure time of 1 s per frame. This highly redundant data set was corrected for Lorentz and polarisation effects; negligible corrections for crystal decay were also applied. The space group $P2_1/n$ was determined by the program XPREP.[17] The structure was solved by direct methods[18] and refined on F^2 by full-matrix least-squares procedures.[16] The hydrogen atoms were placed geometrically, with N–H distances in 0.91 Å and C–H distances in 0.97 Å, and these atoms were refined using a riding model.

Table 1 contains summary data relating to the crystal structures and their refinements. Full details have been deposited with the Cambridge Crystallographic Data Base under deposition numbers 669731 and 669732 and can be obtained through deposit@ccdc.cam.ac.uk.

2.4. General procedure for the conduct of Suzuki coupling

Reactions were carried out in a glass ampoule equipped with a Teflon screw cap. Aryl halide (1.0 mmol), phenylboronic acid (1.1 mmol), Na_2CO_3 (2.0 mmol), TBAB(1.0 mmol) and *n*-dodecane (15–20 mg) as an internal GC standard were dispersed in H_2O (3 mL) and then a solution of the catalyst, e.g., **1**, [Pd(**L1**)Cl]CF3SO3, in H_2O (1.0 μmol mL^{-1}) was added to the mixture. The resulting mixture was stirred at the appropriate temperature (see Tables 2 and 3). Samples were withdrawn periodically and analysed by

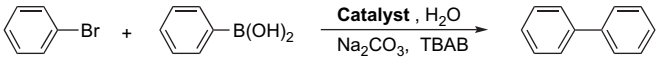
Table 1
Crystal and refinement data

Compound	[Pd(**L1**)Cl]CF_3SO_3	[Pd(**L2**)Cl]ClO_4
Chemical formula	$C_{12}H_{17}ClF_3N_3O_3PdS$	$C_{18}H_{23}Cl_2N_3O_4Pd$
M/g mol^{-1}	482.20	522.69
Crystal system	Orthorhombic	Monoclinic
Space group	*Pbca*	$P2_1/c$
a/Å	16.2206(6)	11.491(2)
b/Å	10.0931(4)	13.081(3)
c/Å	20.4040(7)	13.646(3)
α/°		
β/°		93.06(3)
γ/°		
V/Å^3	3340.5(2)	2048.3(7)
Z	8	4
D_{calcd}/g cm^{-3}	1.918	1.695
μ/mm^{-1}	1.444 (Mo Kα)	1.196 (λ 0.77 Å)
F(000)	1920	1056
T/K	100(2)	293(2)
Reflections collected	57,088	8533
Independent reflections	3170	4741
'Observed' reflections ($I>2\sigma(I)$)	2801	4480
R_{int}	0.017	0.055
Parameters refined	218	255
R_1	0.025	0.051
wR_2	0.063	0.141
S	1.292	1.023
$\Delta\rho_{min}$/e Å^{-3}	−0.61	−1.24
$\Delta\rho_{max}$/e Å^{-3}	0.83	1.82

Table 2
Geometry of the primary coordination spheres in complexes

	[Pd(**L1**)Cl]CF_3SO_3	[Pd(**L2**)Cl]ClO_4
Distance/Å		
Pd–Cl1	2.3093(8)	2.3007(8)
Pd–N1	2.079(3)	2.032(2)
Pd–N2	2.020(3)	2.031(2)
Pd–N3	2.020(3)	2.061(2)
Angle/°		
Cl1–Pd–N1	96.78(8)	89.30(7)
N1–Pd–N2	90.15(10)	84.52(9)
N2–Pd–N3	84.06(11)	90.07(9)
N3–Pd–Cl1	89.03(8)	96.18(7)

Table 3
Suzuki–Miyaura coupling of bromobenzene with phenylboronic acid[a]



Entry	Catalyst (mol %)	Temperature (°C)	Time (h)	Yield[c] (%)
1	**2** (0.01)	70	1	98
2	**2** (0.005)	70	1.5	97
3	**2** (0.001)	70	5	90
4	**2** (0.0005)	70	24	71
5	**2** (0.01)	50	2	93 (90)
6	**2** (0.01)	40	5	95 (90)
7	**2** (0.01)	25	24	41
8	**2** (0.1)	25	10	92 (90)
9	**3** (0.01)	70	1	91
10	**3** (0.01)	40	5	86
11	**1** (0.01)	70	1.5	92
12	**1** (0.01)	40	5	72
13[b]	**2** (0.01)	70	3	43

[a] Molar ratio: bromobenzene (1.0 mmol), phenylboronic acid (1.1 mmol), Pd complex (0.1–0.0005 mol %), TBAB(1.0 mmol) and Na_2CO_3 (2.0 mmol).
[b] without TBAB.
[c] GC yield determined using *n*-dodecane as an internal standard and based on the amount of bromobenzene employed. Isolated yield is given in parenthesis.

GC/GC–MS. GC yields are based on the amount of aryl halide employed. The reaction mixture was filtered and the filter washed with H_2O and Et_2O several times. The organic phase in the combined filtrates was separated and dried over $MgSO_4$, and the solvent was evaporated under reduced pressure. The product was isolated by column chromatography on silica gel.

3. Results and discussion

The complexes **1**, [Pd(**L1**)Cl]CF_3SO_3, **2**, [Pd(**L2**)Cl]ClO_4 and **3**, [Pd(**L3**)Cl]ClO_4, are all easily prepared from the reactions of $PdCl_2$ with the free ligand in methanol, followed by precipitation with an appropriate poorly-coordinating anion, the limiting factor probably being the slow rate of dissolution of polymeric $PdCl_2$ in the solvent. They are all, even the perchlorate 2, thermally stable to at least 90 °C and do not appear to be sensitive to either oxygen or water.

The crystal structure determinations on the complexes **1** and **2** confirm both the expected nature of the ligands (Fig. 2) and the expected square planar geometry of the PdN_3Cl units (Table 1). In both cases, the ligand adopts a chiral conformation and the complex ion units are devoid of symmetry but centrosymmetric enantiomer pairs can be identified in the lattices. In complex **2**, the benzyl substituent is axially disposed on the five-membered chelate ring and the complicated but well-resolved ^{1}H NMR spectrum obtained when the complex is dissolved in CD_3OD is consistent with retention of this configuration in solution. Lattice interactions are different in the two systems and may be significant in indicating reasons for the differences in catalytic activity of the two complexes, though the exact nature of the catalytically active species has not been established. In complex **1**, the centrosymmetric cation pairs observed in the lattice are linked by reciprocal NH···Cl interactions (N···Cl 3.449(3) Å), which involve the axial NH atoms of the terminal amino group of the ligand, the equatorial NH atoms being involved in hydrogen bonds to triflate-*O* (N···O 2.995(4) Å). Interestingly, the coordinated chlorine atoms are only marginally more distant (Cl···C 3.454(3) Å) from methyl carbon atoms in adjacent, homochiral cations than from N of enantiomeric species. In complex **2**, the axial hydrogen of the terminal amino of **1** has been replaced by the benzyl unit but the equatorial NH retains its ability to interact with O, this time from perchlorate (N···O 3.052(4) Å). Centrosymmetric cation pairs may still be identified but here they are associated with Cl···C(aromatic) contacts ~3.6 Å. As there are no contacts indicative of significant axial coordination to Pd(II) in either structure, these coordinated-Cl contacts may be indicative of primary interactions of the complexes with reaction substrates, which initiate formation of catalytic intermediates.

To characterise a reference reaction, initial studies were made of the coupling of bromobenzene and phenylboronic acid with 0.01 mol % of **2** as catalyst in the presence of Na_2CO_3 and tetrabutylammonium bromide (TBAB) (see Table 3). The reaction proceeded to completion at 70 °C within 1 h (entry 1). When the catalyst loading was decreased to 0.001 mol %, high conversion was still achieved (entries 3). Indeed, the reaction remained efficient even when using a much lower catalytic loading of 0.0005%, for which an ultra-high TOF of 592,000 h^{-1} was obtained (entry 4). Further optimisation of the reaction conditions was not attempted. Catalyst **2** still showed outstanding performance at lower temperatures of 25–50 °C (entry 5–8), its activity at 25 °C (entry 8) being particularly noteworthy. In the absence of TBAB, the reaction was inefficient, giving only 28% yield (entry 13). The poor dispersion of the hydrophobic substrate in water in the absence of a surfactant might be the reason. Various roles for TBAB, including possibly stabilisation of a species $[R_4N]^+[ArB(OH)_3]^-$ may in fact be anticipated. Improved dispersion of the organic substrates in the water would result effectively in increased concentrations of reactants and the formation of a complex between the boronic acid and the ammonium salt would favour Suzuki coupling over hydrodeboronation.[19] The catalyst was found to be very stable to oxygen and moisture, only very minor changes in its activity being

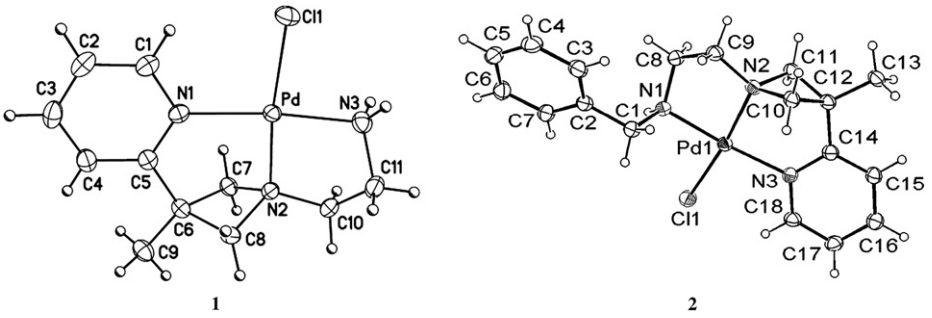


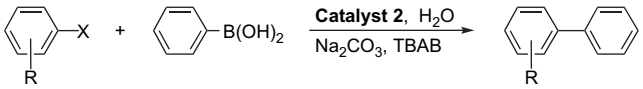
Figure 2. Cations present in the lattices of [Pd(**L1**)Cl]CF_3SO_3,**1**, and [Pd(**L2**)Cl]ClO_4, **2**.

observed on exposure of the system to air and water during the Suzuki reaction. Functionalisation of the ligand has significant effects on the catalyst activity, the complexes **1** and **3** giving yields of 71 and 81% at 40 °C, respectively. The complex **1**, lacking a substituent on the terminal amino group, seems generally a slightly inferior catalyst to **2** and **3**, perhaps reflecting the greater ability of a secondary N-donor to enhance electron density on Pd and thus to facilitate intermediate oxidative addition steps. The additional (pyridine-N) coordinating centre in **3** may have some influence, though, as for the benzyl group in **2**, it is possible that the influence of the pendent arms is due to agostic CH···Pd interactions.

To further extend the scope of our Pd catalytic system, we next investigated the coupling of various aryl halides with phenylboronic acid. As shown in Table 4, high catalytic activity was observed in the coupling of deactivated aryl bromides such as 2-bromoanisole, 4-bromoanisole, 2-bromo-toluene, 4-bromotoluene and 4-bromo phenol (entries 2–6) as well as activated 1-bromo-4-nitro benzene (entry 1). Regardless of the substituents, all of the aryl bromides were rapidly coupled in the presence of **1**. A catalyst loading of 0.01 mol % was sufficient to achieve high TOFs. Deactivated aryl bromides possessing electron-donating groups showed a slight drop in reactivity compared to those with electron-withdrawing groups. However, all of the reactions were complete at 50 °C in less than 3 h. Encouraged by these results, we investigated the coupling of several aryl chlorides (entries 7–19). It is well known that C–Cl is much less reactive than C–Br. Catalyst **1** showed outstanding performance at low temperatures of 50–90 °C (entries 7–13). The coupling of chlorobenzene at 50 °C in the presence of 1 mol % of **1** proceeded rapidly, giving 91% yield in 6 h, although when the loading was decreased to 0.01 mol %, only 39% yield was obtained in 24 h under otherwise identical conditions (entry 7). Activated 1-chloro-4-nitrobenzene was coupled almost quantitatively in 5 h at 90 °C with 0.1 mol % catalyst (entry 14) but this high temperature was necessary to reach satisfactory conversion. Attempts to couple deactivated aryl chlorides were successful to some extent. The reactions of 2-chloroanisole, 4-chloroanisole and 4-chlorotoluene with phenylboronic acid proceeded smoothly but required more extended reaction times to afford the same high yields. Homocoupling products such as biphenyl were observed in the reactions with 2-chloroanisole (entry 15) and 2-chlorotoluene (entry 17) but a higher catalyst loading depressed the formation of this byproduct (entry 18).

Table 4
Suzuki coupling of various aryl halides with arylboronic acid[a]

Entry	Substrate	Temperature (°C)	**2** (mol %)	Time (h)	Yield[b] (%)
1	1-Bromo-4-nitrobenzene	50	0.01	2	99
2	2-Bromo-anisole	50	0.01	3	94
3	4-Bromo-anisole	50	0.01	3	93
4	2-Bromo-toluene	50	0.01	3	92
5	4-Bromo-toluene	50	0.01	3	93
6	4-Bromo-phenol	50	0.01	3	91
7	Chlorobenzene	50	0.01	24	39
8	Chlorobenzene	50	0.1	12	83
9	Chlorobenzene	50	1	6	91
10	Chlorobenzene	70	0.1	10	93
11	Chlorobenzene	70	1	5	96
12	Chlorobenzene	90	0.01	18	87
13	Chlorobenzene	90	0.1	6	95 (92)
14	1-Chloro-4-nitrobenzene	90	0.1	5	96
15	2-Chloro-anisol	90	0.1	10	80/7[c]
16	4-Chloro-anisol	90	0.1	8	93
17	2-Chloro-toluene	90	0.1	10	75/8[c]
18	2-Chloro-toluene	90	1	5	90
19	4-Chloro-toluene	90	0.1	8	91



[a] Molar ratio: aryl halide (1.0 mmol), phenylboronic acid (1.1 mmol), Pd complex **2**, TBAB(1.0 mmol) and Na_2CO_3 (2.0 mmol).
[b] GC yield determined using *n*-dodecane as an internal standard and based on the amount of arylbenzene employed. Isolated yield is given in parenthesis.
[c] The GC yield of biphenyl.

4. Conclusion

New palladium(II) complexes containing functionalised pyridylazetidine ligands can be used as highly efficient catalysts for Suzuki coupling reactions in aqueous dispersions. Various aryl bromides undergo coupling with phenylboronic acid under particularly mild conditions and the catalyst system is also effective for the reactions of aryl chlorides. Further studies of other coupling reactions catalysed by this system are currently in progress.

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