APPLIED ORGANOMETALLIC CHEMISTRY
Appl. Organometal. Chem. 2005; **19**: 870–874
Materials, Nanoscience and Catalysis **AOC**
DOI:10.1002/aoc.922

Benzimidazolin-2-ylidene–palladium-catalysed coupling reactions of aryl halides

Yetkin Gök[1], Nevin Gürbüz[1], İsmail Özdemir[1]*, Bekir Çetinkaya[2] and Engin Çetinkaya[2]

[1]Inönü University, Faculty Science and Arts, Department of Chemistry, 44280 Malatya, Turkey
[2]Department of Chemistry, Ege University, 35100 Bornova-İzmir, Turkey

Received 16 December 2005; Accepted 21 February 2005

The *in situ* prepared three-component system $Pd(OAc)_2$–1,3-dialkylbenzimidazolium chlorides (2a–f) and Cs_2CO_3 catalyses, quantitatively, the Suzuki cross-coupling of deactivated aryl chlorides and Heck coupling reactions of aryl bromide and iodide substrates. The 1,3-dialkylbenzimidazolium salts (2a–f) were characterized by conventional spectroscopic methods and elemental analysis. Copyright © 2005 John Wiley & Sons, Ltd.

KEYWORDS: Heck; Suzuki; carbene; palladium; aryl halides; dialkylbenzimidazolium

INTRODUCTION

An important goal in organic chemistry is the development of green processes that use fewer raw materials and less energy, maximize the use of renewable resources, and minimize or eliminate the use of dangerous chemicals. Clearly, none of this is possible without catalysis. In general, as the science of accelerating chemical reactions, catalysis is about using value-added transformations to convert simple raw materials to more complex molecules with versatile application characteristics. In this regard, palladium catalysts have emerged as extremely powerful tools for the construction of carbon–carbon (Scheme 1) and carbon–heteroatom bonds.[1,2]

Numerous review articles have documented the increasing frequency with which palladium-catalysed coupling processes are applied to a wide array of endeavours, which range from synthetic organic chemistry to materials science. Their popularity stems in part from their tolerance for many functional groups, which allows them to be employed in the synthesis of highly complex molecules.[3–6] The palladium-catalysed reaction of aryl chlorides with arylboronic acid (the Suzuki reaction) or with alkenes (the Heck reaction) is one of the most common methods for C–C bond formation and has attracted much current interest.[7–11] The reactions are usually carried out homogeneously in the presence of a base under inert atmosphere.

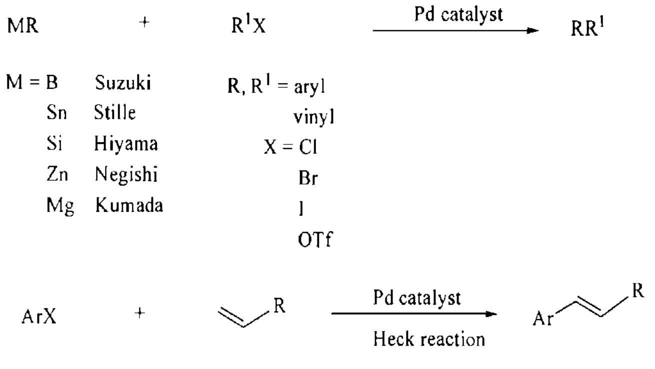
Lately, various bulky and electron-rich phosphines have been developed as ligands to promote the cross-coupling reaction.[12,13] The ligands may afford coordinatively unsaturated monophosphine-ligated complexes and accelerate the catalytic steps, i.e. oxidative addition, transmetalation, and reductive elimination. As a result, even relatively less-reactive aryl chlorides can be used effectively in these coupling reactions.[14]

Recently, it has been shown that palladium complexes of *N*-heterocyclic carbene (NHC) ligands offer distinct advantages as possible alternatives to palladium–phosphine systems in C–C coupling reactions.[15–21] Some highly active palladium systems with monodentate carbene ligands for the activation of aryl chlorides have been developed.[22–24] It is worth noting that '*in situ*' formation of the NHC complex by deprotonation of the imidazol(in)ium salt led to significantly better results than the use of the preformed complex.

In order to find more efficient palladium catalysts, we have prepared a series of new bulky or functional 1,3-dialkylbenzimidazolium chlorides (**2a**–**f**) (Scheme 2) containing a benzimidazole ring. Herein, we report a mild, practical *in situ* generated catalytic system composed of commercially available and stable reagents, using $Pd(OAc)_2$ as the palladium source, 1,3-dialkylbenzimidazolium chlorides (**2a**–**f**) as carbene precursors and Cs_2CO_3 as a base for Suzuki and Heck cross-coupling of aryl halides.

---

*Correspondence to: İsmail Özdemir, Inönü University, Faculty of Science and Arts, Department of Chemistry, 44280 Malatya, Turkey.
E-mail: iozdemir@inonu.edu.tr
Contract/grant sponsor: TÜBİTAK; Contract/grant number: TÜBİ TAK COST D17; TBAG-2474 (104T085).
Contract/grant sponsor: Inönü University Research Fund.



Scheme 1.

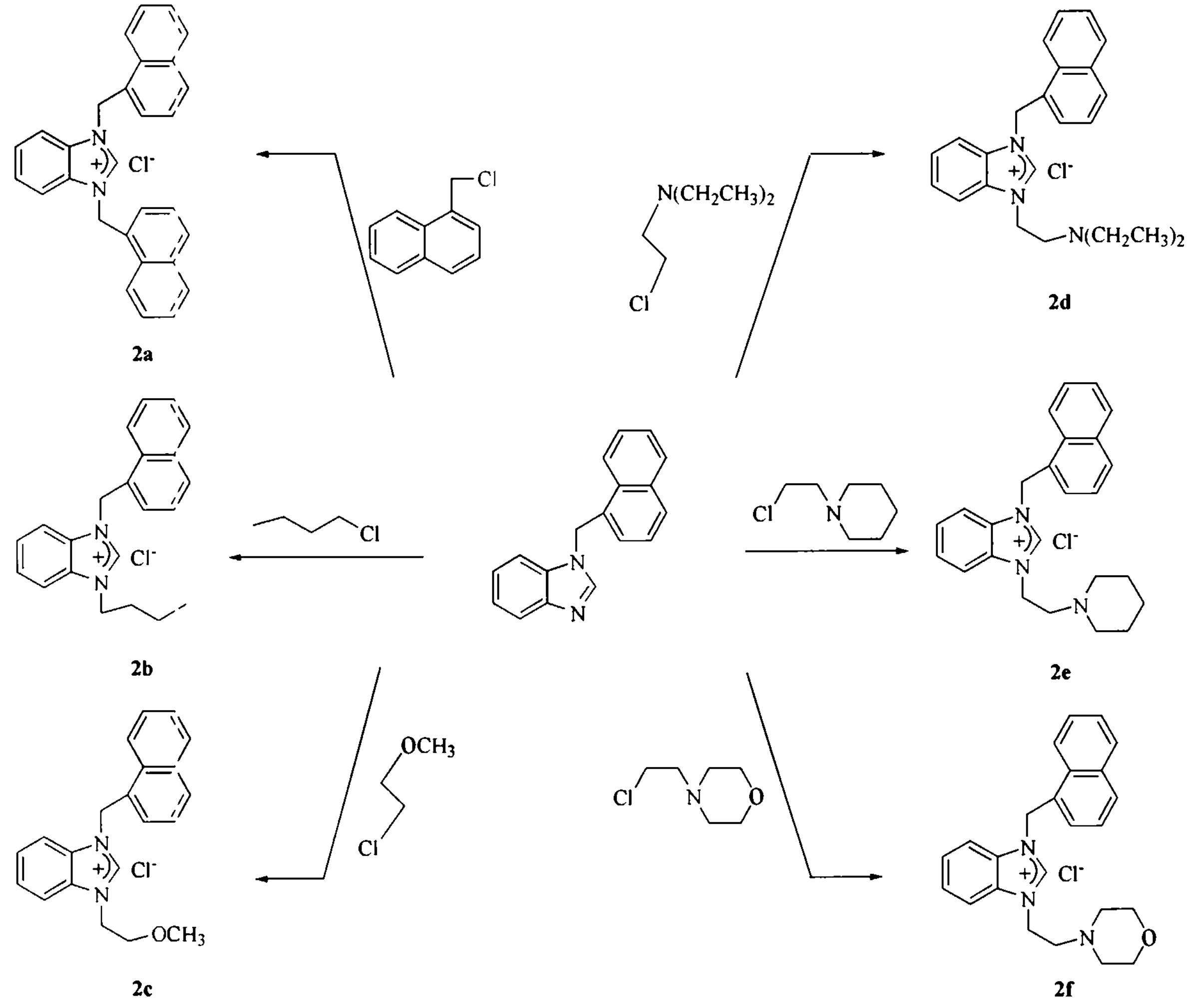
EXPERIMENTAL

All reactions for the preparation of 1-naphthalenomethylbenzimidazoline[25] and 1,3-dialkylbenzimidazolium salts were carried out under argon using standart Schkenk-type flasks. Test reactions for the catalytic activity of catalysts in the Suzuki and Heck cross-coupling reactions were carried out in air. All reagents were purchased from Aldrich Chemical Co. The solvents, Et_2O over Na–K alloy, dimethylformamide (DMF) over BaO, and EtOH over Mg, were distilled prior to use.

All ^1H and ^{13}C NMR spectroscopy was performed in $CDCl_3$. ^1H NMR and ^{13}C NMR spectra were recorded using a Bruker AC300P FT spectrometer operating at 300.13 MHz (^1H) or 75.47 MHz (^{13}C). Chemical shifts δ are given in parts per million relative to tetramethylsilane, coupling constants J are given in hertz. FT-IR spectra were recorded on a Mattson 1000 spectrophotometer, and wavenumbers are in reciprocal centimetres. Melting points were measured in open capillary tubes with an Electrothermal-9200 melting-point apparatus and are uncorrected. Elemental analyses were performed by TUBITAK (Ankara, Turkey) Microlab.

Preparation of 1,3-di(naphthalenomethyl) benzimidazolium chloride (2a)

To a solution of 1-naphthalenomethylbenzimidazoline[25] (2 g; 7.75 mmol) in DMF (3 ml) was added slowly



Scheme 2. Synthesis of 1,3-dialkylbenzimidazolium chlorides.

1-chloromethylnaphthalene (1.38 g; 7.81 mmol) at 25 °C. The resulting mixture was stirred at room temperature for 4 h and then heated for 12 h at 80 °C. Diethyl ether (10 ml) was added to obtain a white crystalline solid, which was filtered off. The solid was washed with diethyl ether (3 × 10 ml), dried under vacuum and recrystallized from $EtOH/Et_2O$ (1 : 2) at room temperature. M.p. 227–228 °C; yield: 2.4 g, 72%, $\nu_{(CN)} = 1558\ cm^{-1}$.

Anal. Found: C, 80.18; H, 5.30; N, 6.52. Calc. for $C_{29}H_{23}ClN_2$: C, 80.08; H, 5.33; N, 6.44%.

^1H NMR (*δ*, $CDCl_3$): 6.39 [s, 4H, $CH_2C_{10}H_7$], 7.27 and 8.22 [m, 18H, Ar-*H*], 12.15 [s, 1H, 2-C*H*]. $^{13}C\{H\}$ NMR (*δ*, $CDCl_3$): 51.4 [$CH_2C_{10}H_7$]; 111.2, 123.0, 135.9, 123.8, 125.7, 126.5, 127.1, 128.5, 129.3, 130.9, 132.1, 133.6, 133.6 [Ar-C]; 144.3 [2-CH].

Preparation of 1-naphthalenomethyl-3-butyl-benzimidazolium chloride (2b)

Compound **2b** was prepared in the same way as **2a**, from 1-naphthalenomethylbenzimidazoline (2.31 g; 13.27 mmol) and butyl chloride (2.35 g; 13.30 mmol), to give white crystals (4.00 g, 86% yield); m.p. 122–123 °C; $\nu_{(CN)} = 1560\ cm^{-1}$.

Anal. Found: C, 75.43; H, 6.68; N, 8.01. Calc. for $C_{22}H_{23}ClN_2$: C, 75.31; H, 6.61; N, 7.98%.

^1H NMR (*δ*, $CDCl_3$): 0.96 [t, 3H, *J* = 7.6 Hz, $CH_2CH_2CH_2CH_3$]; 1.42 [hep, 2H, *J* = 8 Hz, $CH_2CH_2CH_2CH_3$]; 2.01 [quin, 2H, *J* = 7.6 Hz, $CH_2CH_2CH_2CH_3$]; 4.62 [t, 2H, *J* = 7.6 Hz, $CH_2CH_2CH_2CH_3$]; 6.39 [s, 2H, $CH_2C_{10}H_7$]; 7.39 and 8.26 [m, 11H, Ar-*H*]; 11.85 [s, 1H, 2-C*H*]. $^{13}C\{H\}$ NMR (*δ*, $CDCl_3$): 13.7, 19.9, 31.4, 47.7 [$CH_2CH_2CH_2CH_3$]; 49.7 [$CH_2C_{10}H_7$]; 114.4, 123, 125.4, 126.6, 126.9, 127, 127.6, 127.7, 128.7, 129.2, 130, 130.9, 131.6, 131.7, 133.7 [Ar-C]; 144.2 [2-CH].

Preparation of 1-naphthalenomethyl-3-(2-methoxyethyl)benzimidazolium chloride (2c)

Compound **2c** was prepared in the same way as **2a**, from 1-naphthalenomethylbenzimidazoline (2.10 g; 11.93 mmol) and 2-methoxyethyl chloride (1.78 ml; 11.95 mmol), to give white crystals (4.00 g, 95% yield); m.p. 208–209 °C; $\nu_{(CN)} = 1562\ cm^{-1}$.

Anal. Found: C, 71.57; H, 5.71; N, 7.93. Calc. for $C_{21}H_{21}ClN_2O$: C, 71.48; H, 5.60; N, 7.94%.

^1H NMR (*δ*, $CDCl_3$): 3.34 [s, 3H, OCH_3]; 3.98 [t, 2H, *J* = 4.8 Hz, $CH_2CH_2OCH_3$]; 4.88 [t, 2H, *J* = 4.4 Hz, $CH_2CH_2OCH_3$]; 6.33 [s, 2H, $CH_2C_{10}H_7$]; 7.44 and 8.23 [m, 11H, Ar-*H*], 11.84 [s, 1H, 2-C*H*]. $^{13}C\{H\}$ NMR (*δ*, $CDCl_3$): 48.1, 49.7, 70.5 [$CH_2CH_2OCH_3$]; 59.2 [$CH_2C_{10}H_7$]; 113.8, 114.4, 122.9, 125.5, 126.7, 126.9, 127, 127.4, 127.8, 128.4, 129.3, 130.2, 130.9, 131.5, 132.5, 134 [Ar-C]; 144.5 [2-CH].

Preparation of 1-naphthalenomethyl-3-(2-diethylaminoethyl)benzimidazolium chloride (2d)

Compound **2d** was prepared in the same way as **2a**, from 1-naphthalenomethylbenzimidazoline (1.10 g; 4.26 mmol) and 2-diethylaminoethyl chloride (0.58 g; 4.27 mmol), to give white crystals (1.32 g, 79% yield); m.p. 228–229 °C; $\nu_{(CN)} = 1563\ cm^{-1}$.

Anal. Found: C, 73.21; H, 7.15; N, 10.72. Calc. for $C_{24}H_{28}ClN_3$: C, 73.17; H, 7.16; N: 10.67%.

^1H NMR (*δ*, $CDCl_3$): 1.00 [t, 6H, *J* = 6.4 Hz, $(NCH_2CH_3)_2$]; 2.40 [q, 4H, *J* = 6.4 Hz, $(NCH_2CH_3)_2$]; 2.59 [m, 2H, NCH_2CH_2N]; 3.45 [m, 2H, NCH_2CH_2N]; 6.09 [s, 2H, $CH_2C_{10}H_7$]; 7.04 and 7.84 [m, 11H, Ar-*H*]; 11.70 [s, 1H, 2-C*H*]. $^{13}C\{H\}$ NMR (*δ*, $CDCl_3$): 18.7, 46.4 [$(NCH_2CH_3)_2$]; 53.4, 52.6 [NCH_2CH_2N]; 57.8 [$CH_2C_{10}H_7$]; 113.7, 114.0, 122.8, 125.5, 126.6, 126.9, 127, 127.3, 127.7, 128.1, 129.2, 130.2, 130.8, 131.4, 132.5, 134 [Ar-C]; 144.4 [2-CH].

Preparation of 1-naphthalenomethyl-3-(2-piperidinoethyl)benzimidazolium chloride (2e)

Compound **2e** was prepared in the same way as **2a**, from 1-naphthalenomethylbenzimidazoline (1.30 g; 5.03 mmol) and 2-chloromethylpiperidine (0.75 g; 5.04 mmol), to give white crystals (1.79 g, 89% yield); m.p. 233–234 °C; $\nu_{(CN)} = 1567\ cm^{-1}$.

Anal. Found: C, 73.73; H, 6.90; N, 10.38. Calc. for $C_{25}H_{28}ClN_3$: C, 73.69; H, 6.95; N, 10.35%.

^1H NMR (*δ*, $CDCl_3$): 2.07 [m, 2H, $NCH_2CH_2CH_2CH_2CH_2N$]; 3.13 [m, 4H, $NCH_2CH_2CH_2CH_2CH_2N$]; 3.47 [m, 4H, $NCH_2CH_2CH_2CH_2CH_2N$]; 3.66 [m, 2H, NCH_2CH_2N]; 5.53 [t, 2H, *J* = 7.6 Hz, NCH_2CH_2N]; 6.11 [s, 2H, $CH_2C_{10}H_7$]; 7.41 and 8.61 [m, 11H, Ar-*H*]; 11.23 [s, 1H, 2-C*H*]. $^{13}C\{H\}$ NMR (*δ*, $CDCl_3$): 21.9, 22.7, 52.8 [$NCH_2CH_2CH_2CH_2CH_2N$]; 41.7, 48.8 [NCH_2CH_2N]; 53.8 [$CH_2C_{10}H_7$]; 114.7, 114.8, 123.8, 126.3, 127.1, 127.5, 127.6, 127.8, 128.2, 129.5, 129.6, 130.3, 131.2, 131.8, 132.2, 134.2 [Ar-C]; 144.3 [2-CH].

Preparation of 1-naphthalenomethyl-3-[2-morpholinoethyl]benzimidazolium chloride (2f)

Compound **2f** was prepared in the same way as **2a**, from 1-naphthalenomethylbenzimidazoline (1.00 g; 3.87 mmol) and 2-chloromethylmorpholine (0.58 g; 3.88 mmol), to give white crystals (1.35 g, 85% yield); m.p. 265–266 °C; $\nu_{(CN)} = 1564\ cm^{-1}$.

Anal. Found: C, 70.58; H, 6.49; N, 10.38. Calc. for $C_{24}H_{26}ClN_3O$: C, 70.66; H, 6.42; N, 10.30%.

^1H NMR (*δ*, $CDCl_3$): 2.67 [m, 4H, $N(CH_2CH_2)_2O$]; 3.54 [m, 2H, NCH_2CH_2N]; 3.69 [m, 4H, $N(CH_2CH_2)_2O$]; 5.24 [t, 2H, *J* = 7.6 Hz, NCH_2CH_2N]; 6.30 [s, 2H, $CH_2C_{10}H_7$]; 7.42 and 8.60 [m, 11H, Ar-*H*]; 11.23 [s, 1H, 2-C*H*]. $^{13}C\{H\}$ NMR (*δ*, $CDCl_3$): 44.1, 56.2 [NCH_2CH_2N]; 53.6, 66.7 [$N(CH_2CH_2)_2O$]; 53.9 [$CH_2C_{10}H_7$]; 114.6, 114.7, 123.8, 126.7, 127.2, 127.4, 127.6, 127.9, 128.3, 129.6, 129.8, 130.3, 131.3, 131.8, 132.3, 134.4 [Ar-C]; 144.5 [2-CH].

RESULTS AND DISCUSSION

Dialkylbenzimidazolium salts (**2a**–**f**) are conventional NHC precursors. The functionalized or bulky benzimidazolium salts **2a–f** were synthesized by consecutive alkylation of 1-naphthalenomethylbenzimidazole with alkyl halides (Scheme 2).

According to Scheme 2, the salts **2a–f** were obtained in almost quantitative yield by quarternization of 1-naphthalenomethylbenzimidazole in DMF with alkyl halides.[25–29] The salts are air- and moisture-stable, both in the solid state and in solution. The structures of **2a–f** were determined by their characteristic spectroscopic data and elemental analyses. ^{13}C NMR chemical shifts were consistent with the proposed structure; the imino carbon appeared as a typical singlet in the ^{1}H-decoupled mode at 144.3 ppm, 144.2 ppm, 144.5 ppm, 144.4 ppm, 144.3 ppm and 144.5 ppm respectively for benzimidazolium chlorides **2a–f**. The ^{1}H NMR spectra of the benzimidazolium salts further supported the assigned structures; the resonances for C(2)–H were observed as sharp singlets at 12.15 ppm, 11.85 ppm, 11.84 ppm, 11.70 ppm, 11.23 ppm and 11.23 ppm respectively for **2a–f**. The IR data for benzimidazolium salts **2a–f** clearly indicate the presence of the –C=N–group with a ν(C=N) vibration at 1558, 1560, 1562, 1563, 1567 and 1564 cm^{-1} respectively for **2a–f**. The NMR values are similar to those found for other 1,3-dialkylbenzimidazolium salts.[28,29]

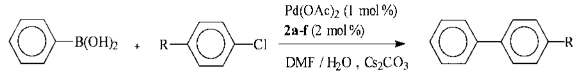
Palladium–NHC-catalysed Suzuki coupling reactions

To find optimum conditions, a series of experiments was performed with 4-chloroanisole and phenylboronic acid as model compounds. As a base, Cs_2CO_3 was the best choice in water–DMF systems. In addition, the reactions were performed in air and without degassing the water prior to use. After having established the optimised coupling reaction conditions, the scope of the reaction and efficiencies of the salts were evaluated by investigating the coupling of $C_6H_5B(OH)_2$ with various para-substituted aryl chlorides. The results are shown in Table 1.

Under these conditions, *p*-chloroacetophenone, *p*-chlorotoluene, *p*-chlorobenzaldehyde, *p*-chloroanisole, and chlorobenzene react very cleanly with phenylboronic acid in good yields (Table 1, entries 4, 9, 16, 22, and 28).

Table 1 summarizes our results from the screening of six benzimidazolium salts, for the Suzuki cross-coupling reaction. Several trends are readily apparent. First, the use of dialkylbenzimidazolium ligand precursors (**2a–f**) allowed lower reaction temperatures (60 °C), shorter reaction times and lower base loadings in aqueous media. The procedure is simple and does not require induction periods. Second, the scope of this reaction is broad and includes aryl chlorides that are activated or deactivated. Third, all complexes led to good conversions at low catalyst concentration (1 mol%, $Pd(OAc)_2$, 2 mol% **2**). It is evident that the NHC precursors that contain electron-donating methoxyethyl or diethylaminoethyl substituents (**2c, 2d**) are the most effective of the salts examined. The coordinating ability of the alkoxy diethylaminoethyl group may be an important contributor to the increase in reactivity, as has been demonstrated by previous examples.[30]

Table 1. The Suzuki coupling reaction of aryl chlorides with phenylboronic acid



Entry	R	LHX	Yield[a,b,c,d] (%)
1	$COCH_3$	**2a**	83
2	$COCH_3$	**2b**	76
3	$COCH_3$	**2c**	91
4	$COCH_3$	**2d**	97
5	$COCH_3$	**2e**	88
6	$COCH_3$	**2f**	86
7	CH_3	**2a**	60
8	CH_3	**2b**	63
9	CH_3	**2c**	74
10	CH_3	**2d**	72
11	CH_3	**2e**	56
12	CH_3	**2f**	57
13	CHO	**2a**	71
14	CHO	**2b**	63
15	CHO	**2c**	85
16	CHO	**2d**	92
17	CHO	**2e**	86
18	CHO	**2f**	85
19	OCH_3	**2a**	70
20	OCH_3	**2b**	77
21	OCH_3	**2c**	81
22	OCH_3	**2d**	83
23	OCH_3	**2e**	64
24	OCH_3	**2f**	67
25	H	**2a**	77
26	H	**2b**	71
27	H	**2c**	88
28	H	**2d**	90
29	H	**2e**	71
30	H	**2f**	68

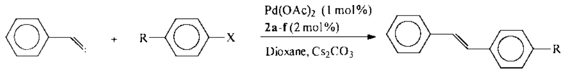
[a] Reaction conditions: 1.0 mmol of *p*-R–C_6H_4Cl, 1.5 mmol of phenylboronic acid, 2 mmol Cs_2CO_3, 1 mmol% $Pd(OAc)_2$, 2 mmol% **2**, water (3 ml)–DMF (3 ml).
[b] Purity of compounds was checked by NMR and yields are based on arylchloride.
[c] All reactions were monitored by thin-layer chromatography (TLC).
[d] Temperature 60 °C, 3 h.

Palladium–NHC-catalysed Heck-type reactions

In initial catalytic experiments, the coupling of *p*-bromoacetophenone and styrene was attempted using the *in situ* formed carbene complexes as pre-catalysts (Table 2, entries 3 and 4). All complexes led to good conversions at low catalyst concentration (1.0 mol%).

Following this, the olefination of styrene with the aryl bromides and iodide were tested, and all produced near-quantitative conversions (entries, 10, 15,

Table 2. The Heck coupling reaction of aryl bromides and iodide with styrene



Entry	R	X	LHX	Yield[a,b,c,d] (%)
1	$COCH_3$	Br	**2a**	62
2	$COCH_3$	Br	**2b**	71
3	$COCH_3$	Br	**2c**	86
4	$COCH_3$	Br	**2d**	91
5	$COCH_3$	Br	**2e**	83
6	$COCH_3$	Br	**2f**	71
7	CHO	Br	**2a**	93
8	CHO	Br	**2b**	90
9	CHO	Br	**2c**	95
10	CHO	Br	**2d**	98
11	CHO	Br	**2e**	58
12	CHO	Br	**2f**	59
13	H	Br	**2a**	68
14	H	Br	**2b**	77
15	H	Br	**2c**	97
16	H	Br	**2d**	97
17	H	Br	**2e**	62
18	H	Br	**2f**	54
19	CH_3O	I	**2a**	85[e]
20	CH_3O	I	**2b**	89[e]
21	CH_3O	I	**2c**	94[e]
22	CH_3O	I	**2d**	98[e]
23	CH_3O	I	**2e**	91[e]
24	CH_3O	I	**2f**	90[e]

[a] Reaction conditions: 1.0 mmol of p-R–C_6H_4Br, 1.5 mmol of styrene, 2 mmol Cs_2CO_3, 1 mmol% $Pd(OAc)_2$, 2 mmol% **2**, dioxane (3 ml).
[b] Purity of compounds is checked by NMR and yields are based on aryl halide.
[c] All reactions were monitered by TLC.
[d] Temperature 80 °C, 2 h.
[e] 1 h.

16, 22). In contrast, the Heck coupling reactions of unactivated (electron-neutral) and deactivated (electron-rich) aryl chlorides, under the same catalytic conditions, did not give a detectable amount of product. The reactivity of the aryl halide component decreases drastically in the order $X = I > Br > Cl$, and electron-withdrawing substituents R are required for the chlorides to react.[1,7–11]

CONCLUSIONS

In conclusion, bulky, electron-rich NHC ligand precursors with a benzimidazolidine backbone, when combined with $Pd(OAc)_2$, give highly active catalysts for the Suzuki coupling reaction; only aryl chlorides are reluctant to give the Heck reaction in the presence of $Pd(OAc)_2$–LHX. The procedure is simple and efficient towards various aryl halides and does not require induction periods. Detailed investigations are ongoing, focusing on imidazolin-2-ylidene and benzimidazolin-2-ylidene substituent effects, functional group tolerance and catalytic activity in this and other coupling reactions.

Acknowledgements

We thank the Technological and Scientific Research Council of Türkiye TÜBİTAK [TÜBİTAK COST D17 and TBAG-2474 (104T085)] and Inönü University Research Fund for financial support of this work.

REFERENCES

1. Herrmann WA. In *Applied Homogeneous Catalysis with Organometallic Compounds*, Cornils B, Herrmann WA (eds). VCH: Weinhem, 1996; 712.
2. Diederich F, Stang PJ (eds). *Metal-Catalyzed Cross-Coupling Reactions*. VCH: Weinhem, 1996.
3. Kotha S, Lahiri K, Kashinath D. *Tetrahedron* 2002; **58**: 9633.
4. Littke AF, Fu GC. *Angew. Chem. Int. Ed.* 2002; **41**: 4176.
5. Suzuki A. *J. Organometal. Chem.* 2002; **653**: 83.
6. Brase S, Kirchhoff JH, Köbberling J. *Tetrahedron* 2003; **59**: 885.
7. Miyaura N, Suzuki A. *Chem. Rev.* 1995; **95**: 2457.
8. Suzuki A. *J. Organometal. Chem.* 1999; **576**: 147.
9. Stanforth SP. *Tetrahedron* 1998; **54**: 263.
10. Whitcombe NJ, Hii KK, Gibson SE. *Tetrahedron* 2001; **57**: 7449.
11. Crisp GT. *Chem. Soc. Rev.* 1998; **27**: 427.
12. Grushin VV, Alper H. *Top. Organometal. Chem.* 1999; **3**: 193.
13. Miura M. *Angew. Chem. Int. Ed.* 2004; **43**: 2201.
14. Herrmann WA. *Angew. Chem. Int. Ed.* 2002; **41**: 1291.
15. Hillier A, Grasa GA, Viciu MS, Lee HM, Yang C, Nolan SP. *J. Organometal. Chem.* 2002; **653**: 69.
16. Özdemir İ, Çetinkaya B, Demir S, Gürbüz N. *Catal. Lett.* 2004; **94**: 37.
17. Özdemir İ, Yiğit M, Çetinkaya E, Çetinkaya B. *Tetrahedron Lett.* 2004; **45**: 5823.
18. Gürbüz N, Özdemir İ, Seçkin T, Çetinkaya B. *J. Inorg. Organometal. Polym.* 2004; **14**: 149.
19. Wang QE, Zhong J, Xie J-H, Li K, Zhou Q-L. *Adv. Synth. Catal.* 2004; **346**: 595.
20. Palencia H, Garcia-Jimenez F, Takacs JM. *Tetrahedron Lett.* 2004; **45**: 3849.
21. Özdemir İ, Alıcı B, Gürbüz N, Çetinkaya E, Çetinkaya B. *J. Mol. Catal. A* 2004; **217**: 37.
22. Zhang C, Huang J, Trudell ML, Nolan SP. *J. Org. Chem.* 1999; **64**: 3804.
23. Böhm VPW, Gstöttmayr CWK, Weskamp T, Herrmann WA. *J. Organometal. Chem.* 2000; **595**: 186.
24. Viciu MS, Germeneau RF, Navarro-Fernandez O, Stevens ED, Nolan SP. *Organometallics* 2002; **21**: 5470.
25. Starikova OV, Dolgushin GV, Larina LI, Ushakov PE, Komarova TN, Lopyrev VA. *Russ. J. Org. Chem.* 2003; **39**: 1536.
26. Haque MR, Rasmussen M. *Tetrahedron* 1994; **50**: 5535.
27. Çetinkaya E, Hitchcock PB, Jasim HA, Lappert MF, Spyropoulos K. *J. Chem. Soc. Perkin Trans. 1* 1992; 561.
28. Tarasova OA, Yu Shmidt E, Baikalova LV, Mikhaleva AI, Trofimov BA. *Izv. Ross. Akad. Nauk Ser. Khim.* 1997; **11**: 2005.
29. Özdemir İ, Gök Y, Gürbüz N, Çetinkaya E, Çetinkaya B. *Heteroat. Chem.* 2004; **15**: 419.
30. Çetinkaya B, Özdemir İ, Bruneau C, Dixneuf PH. *J. Mol. Catal A* 1997; **118**: L1.