Catalytic syntheses and copper- or ruthenium-catalyzed direct C–H bond arylations of (hetero)arenes

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Mein herzlicher Dank gilt meinem verehrten Lehrer

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In Loving Memory of Sri Sathya Sai Baba

Contents

Abbreviations

AAC	azide-alkyne cycloaddition
Ac	acetyl
acac	acetylacetonate
Ad	adamantyl
Alk	alkyl
AMLA	ambiphilic metal-ligand activation
Aq.	aqueous
Ar	aryl
Bn	benzyl
Bu	*n*-butyl
cat.	catalytic
CMD	concerted metalation-deprotonation
COD	cyclooctadiene
dba	dibenzylideneacetone
DG	directing group
DMA	*N*,*N*-dimethylacetamide
DMEDA	*N*,*N*′-dimethylethylenediamine
DMF	*N*,*N*-dimethylformamide
DMSO	dimethylsulfoxid
EI	electron ionisation
equiv	equivalents
ESI	electronspray ionisation
Et	ethyl
et. al.	et alumni
GC	gaschromatography
h	hours
HASPO	hetero-atom substituted secondary phosphine oxide
Hex	*n*-hexyl
IES	internal electrophilic substitution
IR	infrared spectroscopy
L	ligand
M	molar
M	metal
Me	methyl
Mes	mesityl
m.p.	melting point
MS	mass spectrometry
MTBE	methyl *tert*-butyl ether
NMP	*N*-methyl-2-pyrrolidinone
NMR	nuclear magnetic resonance spectroscopy
p	para

PEPPSI	pyridine-enhanced precatalyst preparation stabilization and initiation
Ph	phenyl
ppm	parts per million
SPO	secondary phosphine oxide
temp	temperature
TADDOL	2,2-dimethyl-α,α,α',$\alpha\prime$-tetraphenyl-1,3-dioxolan-4,5-dimethanol
THF	tetrahydrofuran
Tol	tolyl
TM	transition metal
Ts	*p*-toluenesulfonyl
T3P®	propylphosphonic acid anhydride
X-Phos	2-dicyclohexylphosphino-2′,4′,6′-triisopropylbiphenyl

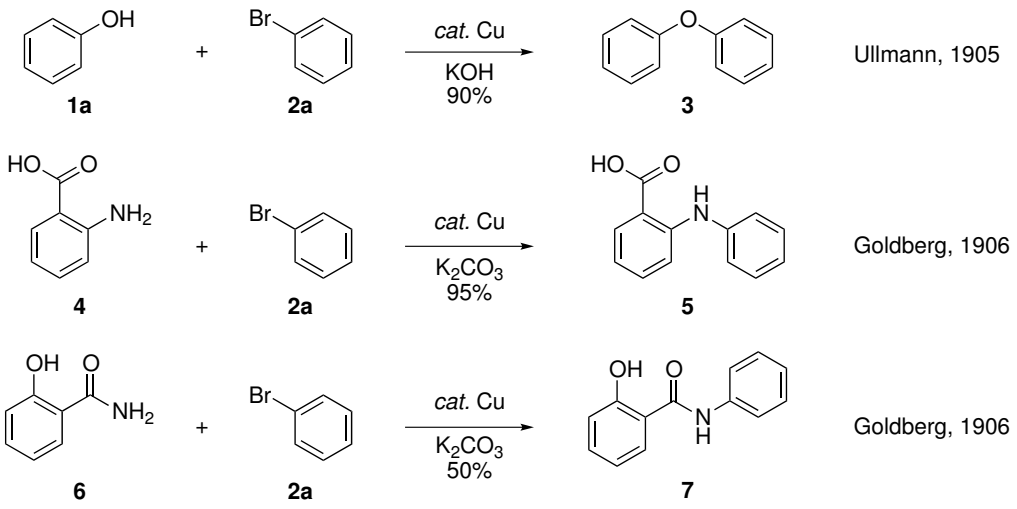
1 Introduction

The importance of *catalysis* to society is apparent. The petroleum, chemical, energy, environmental and pharmaceutical sectors rely on catalysts to produce a variety of products ranging from transportation fuel, new pharmaceuticals, paints to cosmetics. During the last decade, four Nobel prizes in chemistry have been awarded to the field of catalysis (Table 1.1), highlighting its importance in basic research.

Table 1.1: Nobel prizes for catalysis during the last decade.

year	**awardees**	**for**
2001	William S. Knowles Ryoji Noyori K. Barry Sharpless	chirally catalyzed hydrogenation and oxidation reactions
2005	Yves Chauvin Robert S. Grubbs Richard R. Schrock	development of the catalytic metathesis methods
2007	Gerhard Ertl	elucidation of elementary steps in catalytic reactions at the surface of solid-state catalysts
2010	Richard F. Heck Ei-ichi Negishi Akira Suzuki	palladium-catalyzed cross-couplings in organic synthesis

The foundation of modern cross-coupling chemistry was built at the beginning of the twentieth century with the pioneering work of Fritz Ullmann[1,2] and Irma Goldberg (Scheme 1.1).[3] Their explorations into new catalytic methods for the synthesis of C–N and C–O bonds provided the conceptual breakthrough that allowed for the use of unactivated aryl halides to supplant the electron-poor aryl halides typically required for the classical nucleophilic aromatic substitution reaction. Throughout the past several decades, advancements in the field of transition-metal catalysis have provided numerous efficient methods for carbon-carbon bond formation and in turn have allowed for innovative strategies for the synthesis of complex organic molecules.[4]



Scheme 1.1: Copper-catalyzed Ullmann-Goldberg O- and N-arylations.

Arylations *via* transition-metal catalyzed cross-coupling reactions

The use of late transition metals for the synthesis of C–C bonds between two sp^2 hybridized carbons has been well developed and these reactions typically involve the cross-coupling of an aryl (or alkenyl) halide with an organometallic nucleophile.[5,6] These metalated or main-group element species, such as Grignard reagents (Kumada-Corriu), organostannanes (Stille), organoboron reagents (Suzuki-Miyaura) or organozinc reagents (Negishi) allow for the regio- and stereospecific construction of C–C bonds (Figure 1.1).

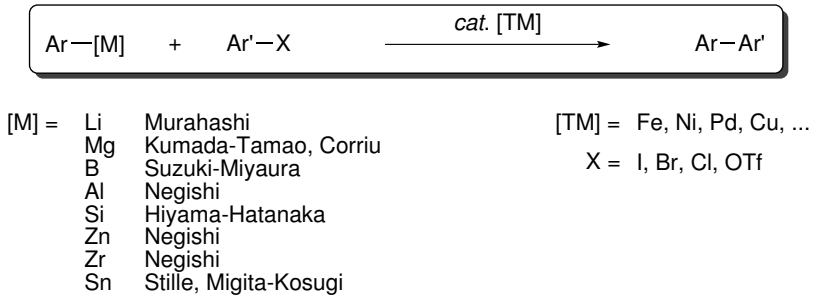
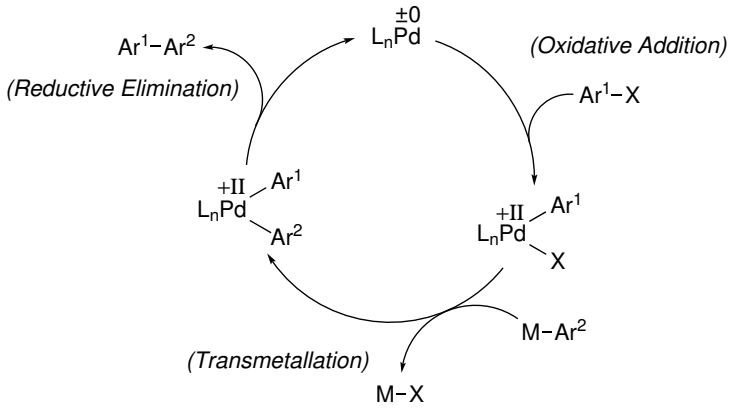


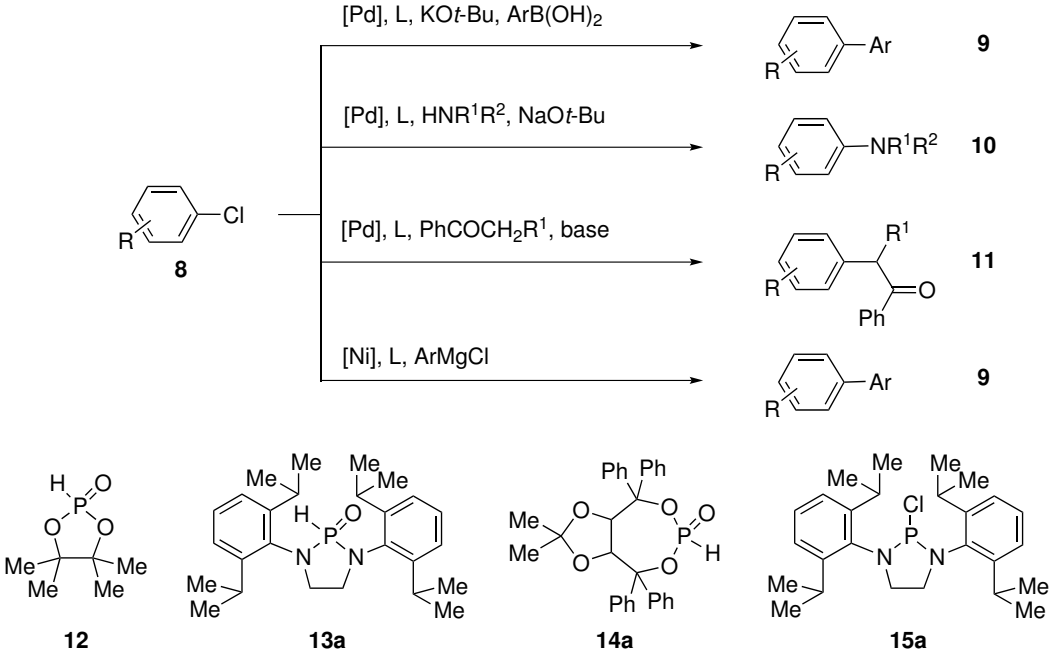
Figure 1.1: Cross-coupling reactions for the synthesis of biaryls.

The mechanism of the reactions which utilize palladium catalysts is believed to proceed *via* a generalized catalytic cycle depicted in Scheme 1.2. This comprises of three stages. First, activation of the electrophilic component occurs via oxidative addition onto the $L_nPd(0)$ center to form $L_nPd(II)Ar^1X$ species. Next, nucleophilic activation or transmetalation of M–Ar^2 occurs to provide $L_nPd(II)Ar^1Ar^2$, which then reductively eliminates to form the desired coupled product (Ar^1–Ar^2) and regenerates the active $L_nPd(0)$ catalyst.[7]



Scheme 1.2: Generalized mechanism for palladium(0)-catalyzed cross-coupling reactions.

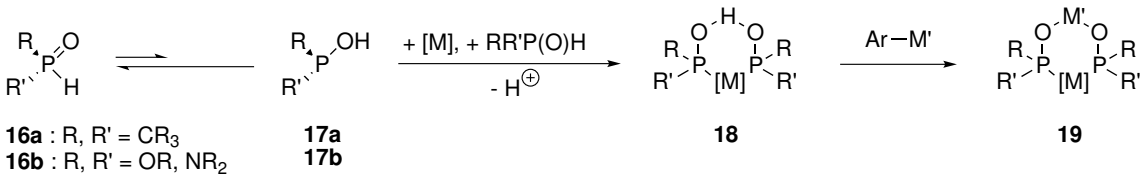
The use of aryl chlorides for these transformations is preferred due to their low cost and easy availability.[8] The recent realization of active catalyst systems can be attributed to an increased focus on the ligand design.[9] Among them, Prof. Ackermann has developed the use of air-stable *h*etero-*a*tom *s*ubstituted *s*econdary *p*hosphine *o*xides (HASPO) for a variety of C–C and C–N bond forming reactions (Scheme 1.3).[10,11]



Scheme 1.3: HASPO preligands for efficient C–C and C–N bond formations.

In solution, secondary phosphine oxides (SPO) exist in equilibrium between pentavalent (phosphine oxides, **16a**; *H*-phosphonates or their derivatives, **16b**) and trivalent (phosphinous acids **17a**; phosphites or their derivatives **17b**) tautomeric structures **16** and **17**, respectively (Scheme 1.4). At ambient temperature the pentavalent phosphorus tautomer strongly predominates, rendering HASPOs overall air- and moisture-stable. However, the equilibrium is shifted in the presence of late-transition metals *via* coordination through

trivalent phosphorus to yield predominantly complexes **18**. Overall, this self-assembly process thus results in the formation of a bidentate ligand system that displays an acidic moiety.[11] Upon displacement by a basic metal or main group element, heterobimetallic compounds of type **19** are generated *in situ* which are believed to be the key intermediates.[10]



Scheme 1.4: Tautomeric forms of SPOs and formation of heterobimetallic complexes **19**.

While considerable progress in Suzuki-Miyaura coupling chemistry has been accomplished in recent years through the development of stabilizing ligands,[12–14] syntheses of highly *ortho*-substituted biaryls continue to constitute a significant challenge. Thus, high-yielding preparations of tetra-*ortho*-substituted biaryls have thus far only been accomplished with palladium complexes derived from biphenyl monophosphines (**20a**–**20c**),[15–19] tertiary phosphine (**21**),[20,21] or *N*-heterocyclic carbenes (**22** and **23**)[22–24] as sterically demanding, electron-rich stabilizing ligands (Figure 1.2).

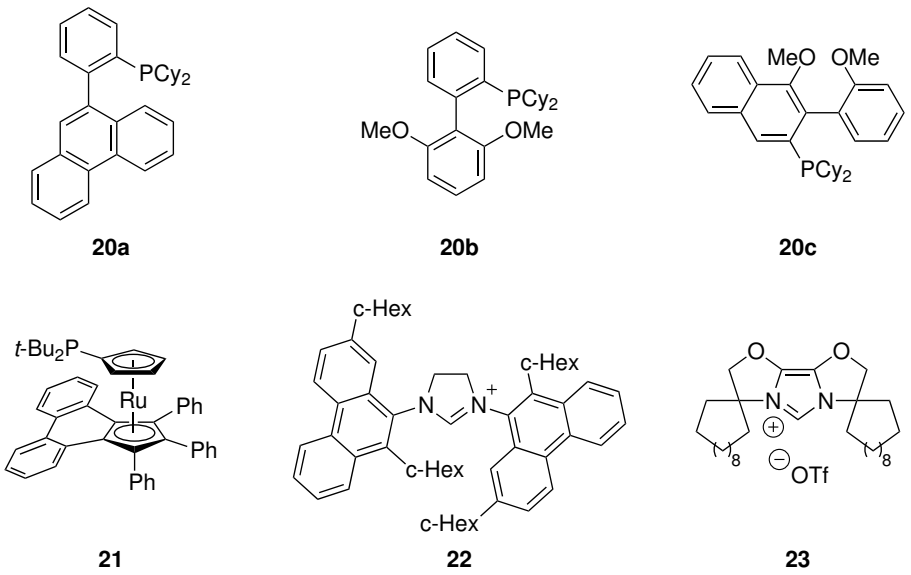
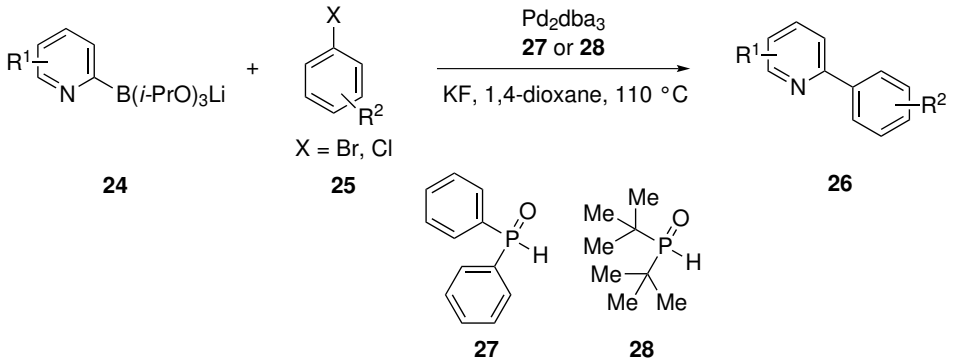


Figure 1.2: Ligands for the synthesis of tetra-*ortho*-substituted biaryls.

Examination of reported results indicated that only a few reports of the Suzuki-Miyaura reaction of 2-pyridyl nucleophiles with aryl halides have appeared.[25,26]. The difficulty of these transformations can be attributed to several factors: (i) electron-deficient heteroaryl boron derivatives undergo transmetalation at a relatively slow rate and (ii) these reagents rapidly decompose *via* a protodeboronation pathway. Buchwald reported on

the use of SPOs **27** and **28** for the Suzuki-Miyaura cross-coupling of lithium triisopropyl 2-pyridylborates (**24**) with aryl bromides and aryl chlorides (Scheme 1.5).[27]

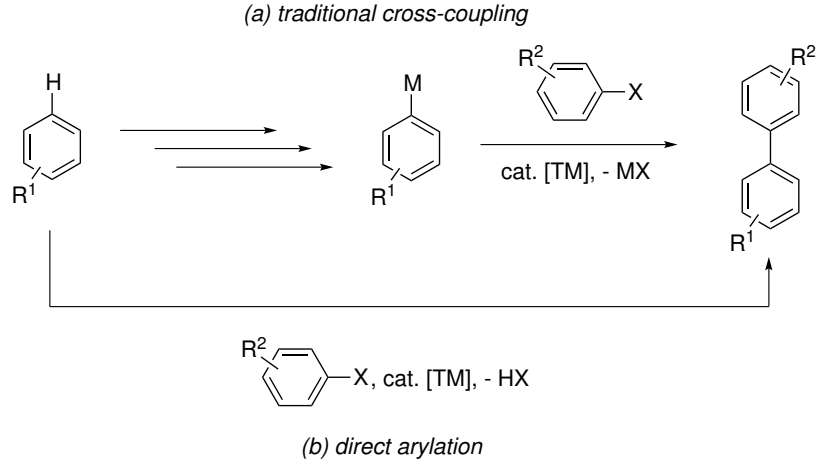


Scheme 1.5: Suzuki-Miyaura cross-coupling of lithium triisopropyl 2-pyridylborates **24**.

Also, Deng *et. al.* reported a copper(I) facilitated palladium-catalyzed Suzuki-Miyaura cross-coupling of 2-pyridylpinacol boronates with aryl (pseudo)halides.[28] Li, Shen and co-workers demonstrated a convenient protocol for the coupling of pyridyl-2-boronic esters with (hetero)aryl halides using a palladium complex derived from **28**.[29]

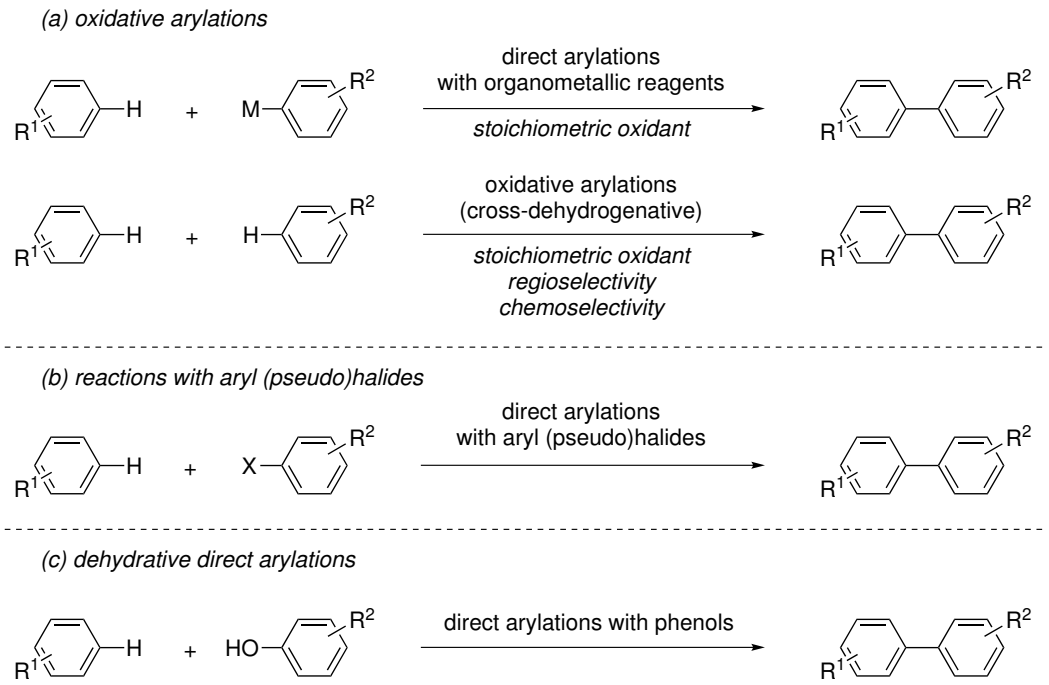
Transition-metal catalyzed direct arylations *via* C–H bond cleavages

During the recent years, direct arylation reactions through C–H bond functionalizations have emerged as an economically and ecologically benign alternative to traditional cross-coupling techniques and are finding increased applications.[4,30–34] This approach avoids the need for stoichiometric organometallic reagents along with the problems associated with their synthesis, stability and functional group compatibility, thus minimizing the synthetic manipulations prior to the cross-coupling reaction (Scheme 1.6).



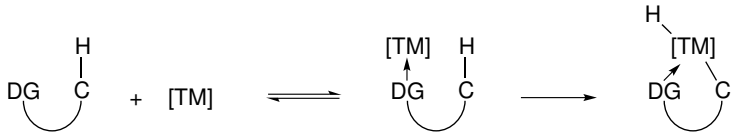
Scheme 1.6: Traditional cross-coupling reactions (a) *versus* direct arylations (b).

Based on the nature of the coupling partners, these direct arylation reactions are classified as (a) oxidative arylations, (b) reactions with aryl (pseudo)halides and (c) dehydrative arylations (Scheme 1.7). The oxidative arylations usually necessitate the need for stoichiometric amounts of organometallic reagents as sacrificial oxidants and dehydrogenative transformations are challenging to perform with equimolar amounts of the starting materials.[35,36] The use of (pseudo)halides is generally more applicable as it avoids the formation of undesired side products.



Scheme 1.7: Strategies for direct arylation based biaryl synthesis.

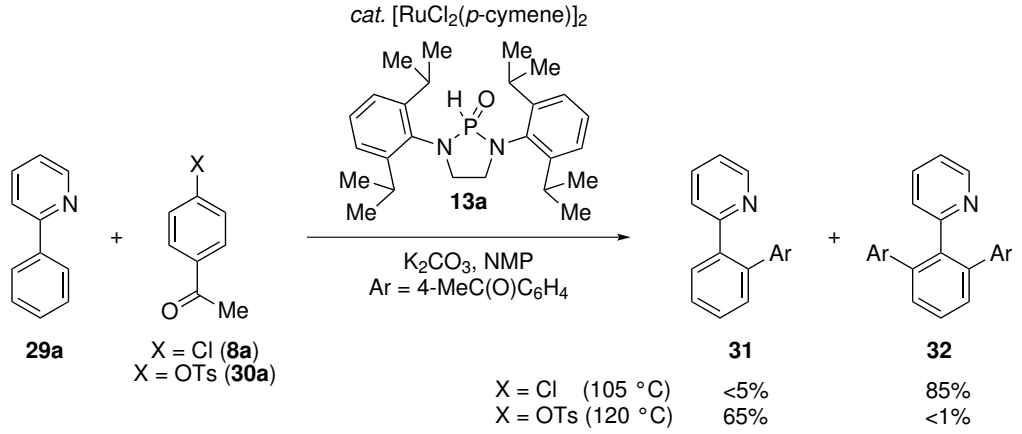
Since organic molecules usually possess a number of C–H bonds with comparable dissociation energies, the development of regioselective methods for direct arylations is a major challenge. The problem may be solved by employing (removable) directing groups. For example, a Lewis-basic directing group coordinates to the transition-metal catalyst, and this enables an intramolecular cleavage of the C–H bond.[37] Such a cyclometalation allows intermolecular direct arylations to be accomplished in a highly regioselective way (Scheme 1.8).



Scheme 1.8: Chelation-assisted C–H bond cleavages.

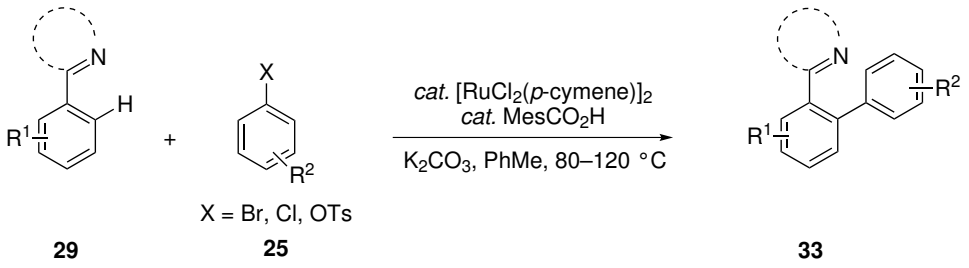
A ruthenium-catalyzed chelation-assisted approach for direct arylations using organometallic reagents and (pseudo)halides is known since 2001.[38] Oi, Inoue and

coworkers disclosed direct arylations of pyridine derivatives using aryl bromides as electrophiles.[39,40] More recently, Ackermann *et. al.* reported a ligand-free system for efficient direct arylations of pyridine derivatives with aryl bromides.[41,42] Employing of HASPO preligands further enabled direct arylations of arenes[43] substituted with pyridine, pyrazole or oxazoline directing groups, with site-selectivities being mainly controlled by steric interactions. On the other hand, the chemoselectivity of the C–H bond arylation with respect to mono- or di-arylation can be controlled by appropriate choice of the electrophile.[44] Hence, the use of aryl chlorides provide the diarylated products, even at reduced reaction temperatures, whilst the corresponding monoarylated compounds were formed with aryl tosylates as the sole products (Scheme 1.9).



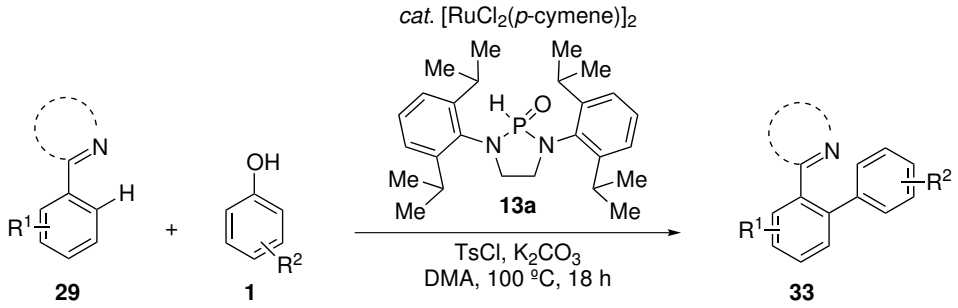
Scheme 1.9: Chemo-selective direct arylations with aryl chlorides and tosylates.

Prof. Ackermann also reported on carboxylate-assisted ruthenium-catalyzed direct arylations in apolar solvents (Scheme 1.10).[45] These reactions were proposed to proceed *via* a concerted metalation-deprotonation mechanism.



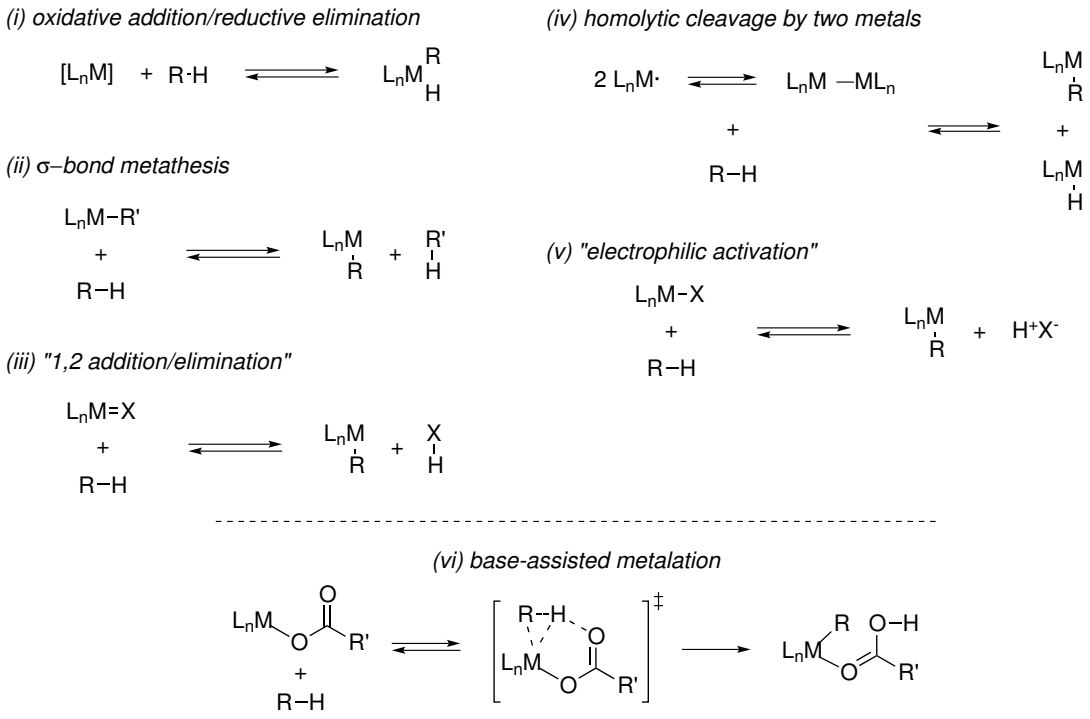
Scheme 1.10: Carboxylate-assisted ruthenium-catalyzed direct arylations.

Subsequently, an operationally simple and sustainable approach for the use of phenols as proelectrophiles in the ruthenium-catalyzed dehydrative direct arylations using HASPO preligand **9** was reported (Scheme 1.11). Interestingly, even carboxylic acids could also be employed as co-catalysts for this atom-economical transformation.[46]



Scheme 1.11: Ruthenium-catalyzed dehydrative direct arylations.

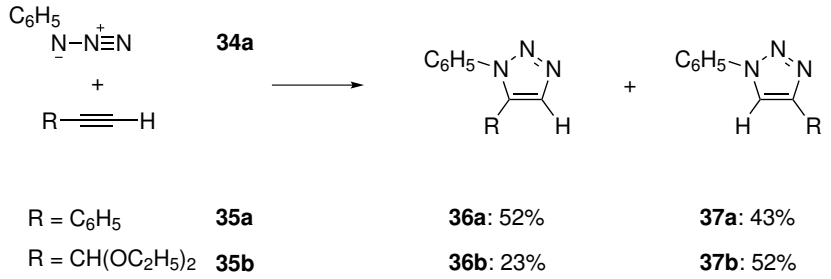
Transition-metal catalyzed C–H bond functionalization reactions are well documented [47] and have been suggested to proceed according to five mechanisms.[48–51] These include (i) oxidative-addition/reductive elimination, (ii) σ–bond metathesis, (iii) 1,2-addition/elimination sequence, (iv) homolytic cleavage of two metals or (v) electrophilic activation (Scheme 1.12).



Scheme 1.12: Different mechanisms for C–H bond activation.

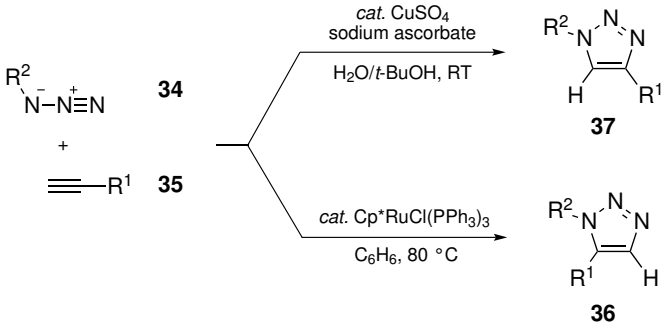
On the other hand, carboxylate assisted C–H bond transformations[52] were mostly proposed to proceed *via* a concerted base-assisted metalation-deprotonation (equation vi in Scheme 1.12). Several acronyms have been introduced to describe this mode of activation, namely CMD (concerted metalation-deprotonation),[53] IES (internal electrophilic substitution)[54] or AMLA (ambiphilic metal-ligand activation).[55]

The synthesis of substituted 1,2,3-triazoles strongly relies on Huisgen′s 1,3-dipolar cycloaddition between organic azides and substituted alkynes.[56] While this technique proved to be highly versatile, the thermal conversion of unsymmetrically-substituted alkynes usually resulted in difficult to separate mixtures of regioisomers (Scheme 1.13).



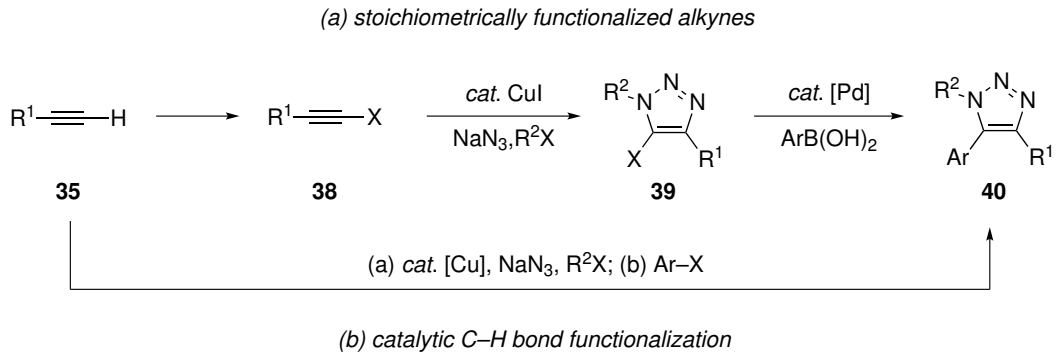
Scheme 1.13: Azide-alkyne [3+2] cycloadditions.

A major advance in improving the regioselectivity of azide-alkyne [3+2]-cycloadditions as well as reaction rate was accomplished by employment of copper compounds as additives. Meldal and coworkers disclosed the use of copper(I) salts for regioselective 1,3-dipolar azide-alkyne cycloadditions (CuAAC).[57] In independent studies, Sharpless, Fokin, and co-workers found a very robust catalytic system for cycloadditions between azides and terminal alkynes,which made use of a less expensive copper(II) precatalyst, along with substoichiometric amounts of sodium ascorbate for an *in situ* reduction.[58] On the contrary, the use of ruthenium(II) complexes furnishes the products with complementary regioselectivity (Scheme 1.14).[59]



Scheme 1.14: Complementary synthesis of di-substituted triazoles.

Recently, focus has shifted towards the development of generally applicable syntheses of 1,4,5-trisubstituted 1,2,3-triazoles. The known strategies include (i) the interception of 5-cuprated-1,2,3-triazoles with electrophiles employing stoichiometric amounts of copper salts, and (ii) conversion of stoichiometrically functionalized, *i.e.* magnesiated or halogenated alkynes to fully-substituted triazoles.[60] However, a more sustainable approach would be the nexus of CuAAC reactions with atom-economical C–H bond functionalizations (Scheme 1.15).

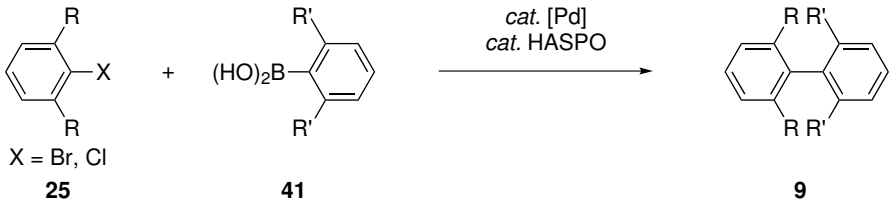


Scheme 1.15: Strategies for catalytic syntheses of fully-substituted 1,2,3-triazoles.

Thus far, all catalytic direct C–H bond functionalizations of 1,2,3-triazoles required the use of palladium complexes as catalysts.[61–63] Particularly the use of inexpensive copper compounds for catalytic C–H bond functionalizations is highly attractive, considering (i) their cost-effective nature, and (ii) their use in CuAAC for the assembly of 1,2,3-triazoles. Daugulis and coworkers have reported on copper-catalyzed direct arylations of heteroarenes.[64,65]

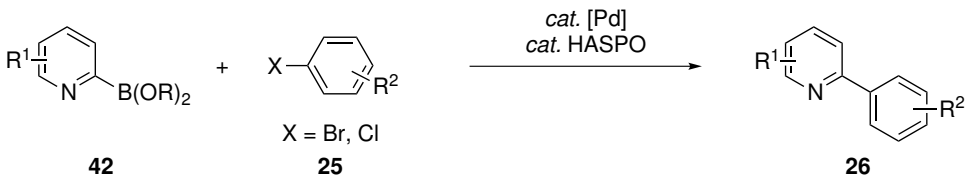
2 Objectives

Prof. Ackermann reported on applications of diaminochlorophosphine **15a** as a ligand for palladium-catalyzed cross-coupling reactions of aryl halides.[11,66–69] While this catalytic system enabled the use of chloroarenes in Suzuki-Miyaura couplings, noteworthy limitations were represented by unsatisfactory low conversions of sterically hindered substrates, as well as the need for KO*t*-Bu as a strong base. As further development of this chemistry, the efficacy of these novel class of ligands for challenging synthesis of sterically hindered biaryls was the prime focus of the first project (Scheme 2.1).



Scheme 2.1: Synthesis of tetra-*ortho*-substituted biaryls.

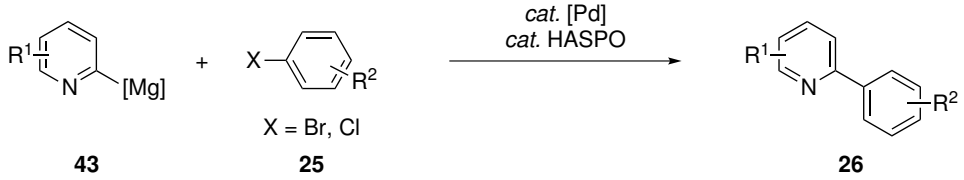
Palladium complexes derived from secondary aryl- or alkyl-substituted phosphine oxides and chlorides were shown to allow for cross-coupling reactions of 2-pyridyl borates[27] or 2-pyridyl boronic esters.[28,70,71] Therefore, it was of high interest to explore the use of HASPO preligands for palladium-catalyzed cross-couplings of 2-pyridylborates (Scheme 2.2).



Scheme 2.2: Suzuki-Miyaura cross-coupling of pyridin-2-yl borates.

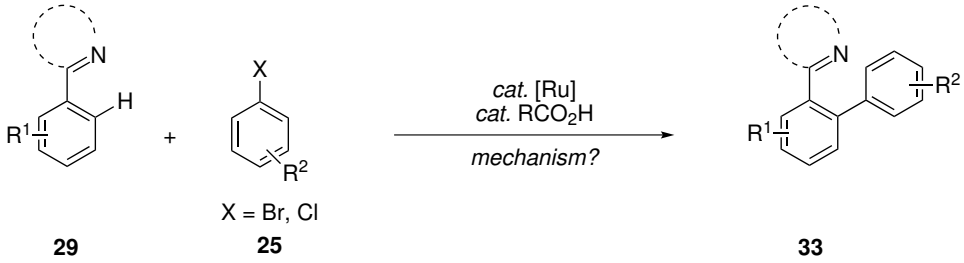
Since organomagnesium reagents are more readily available than alternative organometallic nucleophiles,[72,73] catalytic cross-couplings of Grignard reagents have proven particularly useful for streamlining heterobiaryl synthesis. While this research significantly expanded the pool of viable electrophiles, cross-coupling reactions of electron-deficient *N*-heterocyclic organometallic reagents continue to be challenging because of their reduced nucleophilicities. A generally applicable protocol for metal-catalyzed arylations of less nucleophilic 2-azine Grignard reagents has proven elusive.[26,74–76] The further studies thus

aimed for the development of efficient cross-couplings with 2-pyridyl organomagnesium compounds (Scheme 2.3).



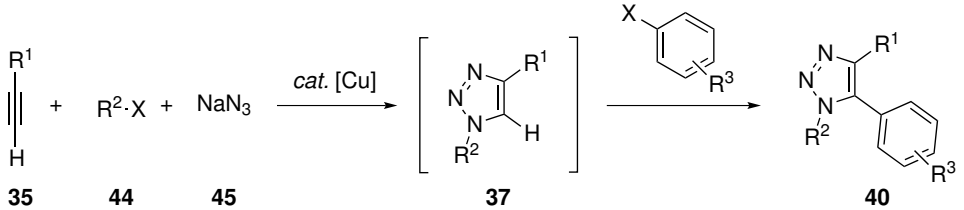
Scheme 2.3: Kumada-Corriu cross-coupling of pyridin-2-yl nucleophiles.

One of the promising modern trends in transition-metal-catlyzed C–H bond functionalizations is the employment of carboxylates as co-catalysts.[52] While co-catalysis with carboxylates in palladium-catalyzed reactions have been investigated in detail,[77] corresponding ruthenium-catalyzed arylations are rather scanty. Ackermann *et.al.* have reported the use of carboxylic acids as co-catalysts for assisted ruthenium-catalyzed direct arylations[45] in apolar solvents *via* a concerted metalation-deprotonation (CMD) mechanism. In light of continued success of these methods, studies to elucidate the mechanism of these reactions was an additional goal (Scheme 2.4).



Scheme 2.4: Carboxylate-assisted ruthenium-catalyzed direct arylations.

Regioselective syntheses of fully substituted 1,2,3-triazoles through 1,3-dipolar cycloadditions were thus far largely limited to either the use of stoichiometric amounts of copper salts in azide-alkyne cycloaddition (AAC) reactions, or stoichiometrically halogenated or metalated alkynes.[60] A more sustainable strategy is therefore represented by transition-metal-catalyzed direct C–H bond functionalizations of 1,2,3-triazoles under mild reaction conditions.



Scheme 2.5: Copper-catalyzed sequential synthesis of fully substituted triazoles.

Consequently, elaboration of reaction conditions for modular syntheses of 1,4,5-trisubstituted 1,2,3-triazoles directly from terminal alkynes and NaN_3 through the use of a single copper catalyst was one of the goals of the present work (Scheme 2.5).

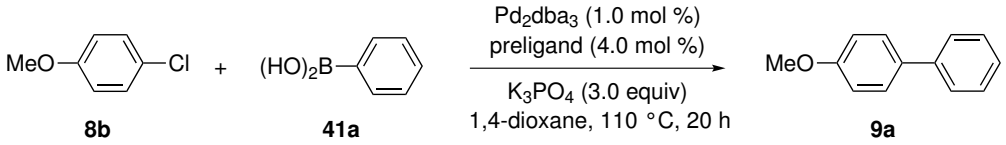
3 Results and Discussion

3.1 Suzuki-Miyaura cross-coupling reactions

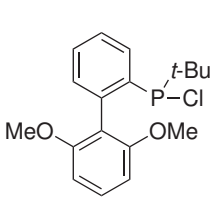
3.1.1 Cross-coupling with aryl chlorides

Suzuki-Miyaura couplings have proven useful because of their remarkable tolerance of functional groups, along with the low toxicities and ready availability of organoboron nucleophiles.[7,12] Ackermann *et. al.* previously reported on the use of diaminophosphine chloride **15a** for the palladium-catalyzed Suzuki-Miyaura cross-coupling[66] of aryl chlorides. In quest for effective phosphine ligands and in continuation of this work, it was observed that biphenyl-substituted phosphine chloride[78] **46** showed excellent reactivity for the reaction of 4-chloroanisole with phenylboronic acid using K_3PO_4 as a mild base in dioxane at 110 °C. The corresponding product was isolated in 93% yield (Chart 3.1).

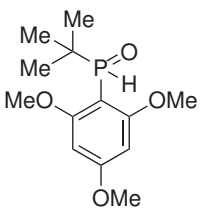
Chart 3.1: Preligands **46**–**48** in the Suzuki-Miyaura cross-coupling with aryl chloride **8b**.[a]



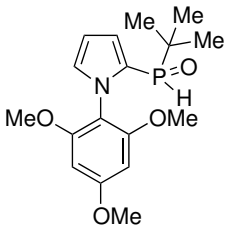
8b **41a** **9a**



46: 93%



47: <5%

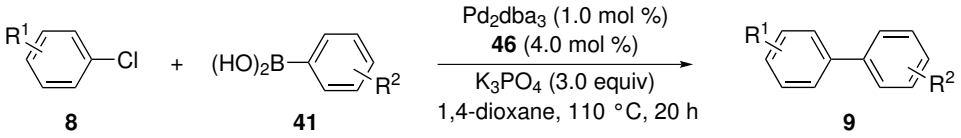


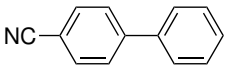
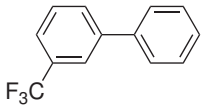
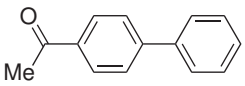
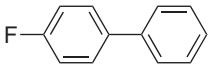
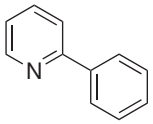
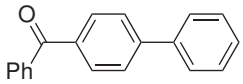
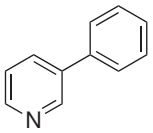
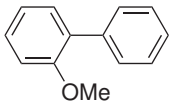
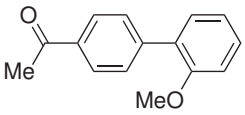
48: <5%

[a] **8b** (0.50 mmol), **41a** (0.75 mmol), $Pd_2(dba)_3$(1.0 mol %), preligand (4.0 mol %), K_3PO_4 (3.0 equiv), 1,4-dioxane (2 mL), 110 °C, 20 h.

The results of exploration of this novel (pre)ligand **46** for Suzuki-Miyaura cross-couplings with various aryl chlorides **8** are shown in Table 3.1. The use of mild base K_3PO_4 allowed the tolerance of sensitive acetyl, nitrile and fluoro functional groups. Even *ortho*-substituted aryl chloride **8j** (entry 8) or arylboronic acid **41b** (entry 9) were successfully cross-coupled.

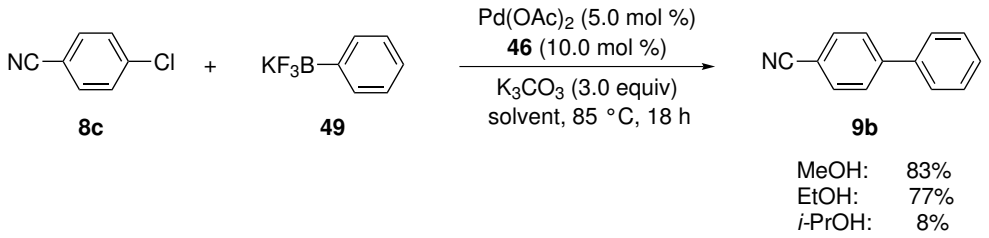
Table 3.1: Scope of Suzuki-Miyaura cross-coupling with aryl chlorides **8**.[a]



entry	R^1		R^2		product		yield (%)
1	4-CN	**8c**	H	**41a**		**9b**	99
2	3-CF_3	**8d**	H	**41a**		**9c**	94
3	4-C(O)Me	**8e**	H	**41a**		**9d**	96
4	4-F	**8f**	H	**41a**		**9e**	94
5	2-py	**8g**	H	**41a**		**9f**	99
6	4-C(O)Ph	**8h**	H	**41a**		**9g**	97
7	3-py	**8i**	H	**41a**		**9h**	87
8	2-MeO	**8j**	H	**41a**		**9i**	89
9	4-C(O)Me	**8e**	2-MeO	**41b**		**9j**	89

[a] **8** (0.50 mmol), **41** (0.75 mmol), $Pd_2(dba)_3$(1.0 mol %), **46** (4.0 mol %), K_3PO_4 (3.0 equiv), 1,4-dioxane (2 mL), 110 °C, 20 h.

The use of phenyltrifluoroborate[79] (**49**) as nucleophilic coupling partner employing pre-ligand **46** as the ligand of choice has been tested as well. Thus, it was observed that the desired 4-cyanobiphenyl (**9b**) was obtained in 83% isolated yield in methanol as the solvent (Scheme 3.1). Whilst ethanol also proved effective, the use of isopropanol resulted in lower efficiency.

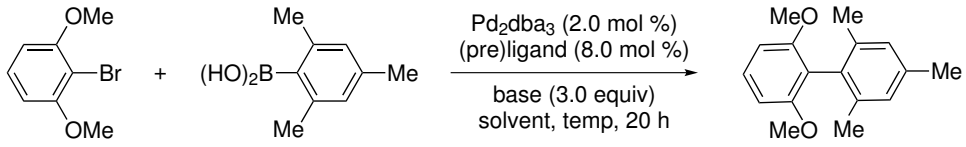


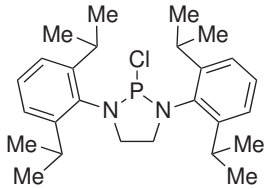
Scheme 3.1: Palladium-catalyzed Suzuki-Miyaura coupling with phenyltrifluoroborate (**49**).

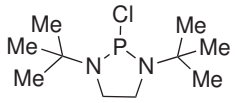
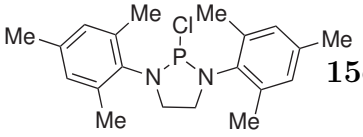
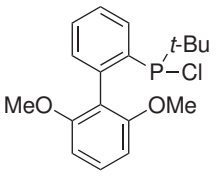
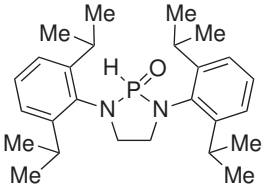
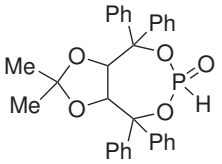
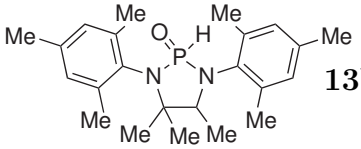
3.1.2 Synthesis of sterically hindered biaryls

At the outset, representative chlorophosphines **15** were probed in the palladium-catalyzed synthesis of tetra-*ortho*-substituted biaryl **9k** *via* Suzuki-Miyaura coupling reaction (Table 3.2). Preliminary experiments with diaminochlorophosphine **15a** revealed 1,4-dioxane to be the solvent of choice. While a variety of bases provided unsatisfactory results (entries 3–11), cesium salts were found to be more effective (entries 12 and 14), with CsF being optimal (entry 14).

Table 3.2: Screening of (pre)ligands for the synthesis of sterically hindered biaryls.[a]



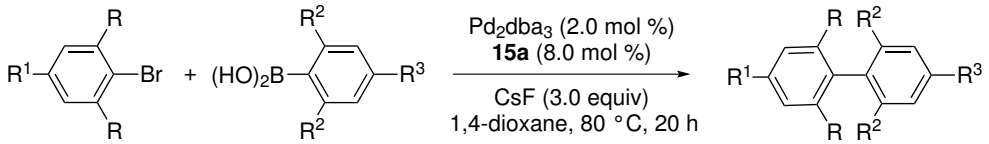
entry	(pre)ligand		base	solvent	temp (°C)	yield (%)
1	-		CsF	1,4-dioxane	80	-
2	PPh_3	**50**	CsF	1,4-dioxane	80	11
3			NaO*t*-Bu	1,4-dioxane	80	-
4			KO*t*-Bu	1,4-dioxane	80	-
5			K_2CO_3	1,4-dioxane	80	-
6			K_3PO_4	1,4-dioxane	80	-
7			KO*t*-Bu	THF	60	-
8		**15a**	K_3PO_4	PhMe	110	-
9			K_3PO_4	1,4-dioxane	110	-
10			CsOAc	1,4-dioxane	80	-
11			KF	1,4-dioxane	80	5
12			Cs_2CO_3	1,4-dioxane	80	35
13			CsF	1,4-dioxane	80	62[b]
14			CsF	1,4-dioxane	80	99

15		**15b**	CsF	1,4-dioxane	80	5
16		**15c**	CsF	1,4-dioxane	80	35
17		**46**	CsF	1,4-dioxane	80	42
18	$(t\text{-Bu})_2\text{PCl}$	**51**	CsF	1,4-dioxane	80	-
19		**13a**	CsF	1,4-dioxane	80	-
20		**14a**	CsF	1,4-dioxane	80	-
21	$(t\text{-Bu})_2\text{P(O)H}$	**28**	CsF	1,4-dioxane	80	-
22		**13b**	CsF	1,4-dioxane	80	-
23	$(\text{OEt})_2\text{P(O)H}$	**52**	CsF	1,4-dioxane	80	5
24	P(OPh)_3	**53**	CsF	1,4-dioxane	80	-

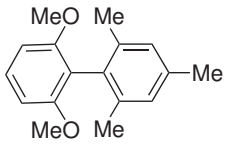
[a] **2b** (0.50 mmol), **41c** (0.75 mmol), $Pd_2(dba)_3$(2.0 mol %), (pre)ligand (8.0 mol %), K_3PO_4 (3.0 equiv), solvent, temperature, 20 h. [b] $Pd_2(dba)_3$ (1.0 mol %), (pre)ligand (4.0 mol %).

Considerable reactivity was observed even when using a lower catalytic loading of the palladium precursor (entry 13). Unfortunately, diaminochlorophosphines **15b** or **15c** only gave rise to significantly less efficient catalysis (entries 15 and 16), as was also observed for biphenyl-substituted phosphine chloride **46** (entry 17). Surprisingly, di-*tert*-butyl phosphine chloride[80,81] did not show any catalytic activity. Moreover, secondary phosphine oxides **13** and **14a** were found to be ineffective for this transformation (entries 19–22). With an optimized catalytic system in hand, I explored the scope of this protocol for the preparation of various tetra-*ortho*-substituted biaryls **9** (Chart 3.2). Thus, diversely substituted products **9k**–**9s** with valuable functional groups, such as esters, amides, or heteroarenes, could be prepared in good isolated yields.

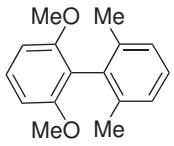
Chart 3.2: Synthesis of tetra-*ortho*-substituted biaryls using aryl bromides.[a]



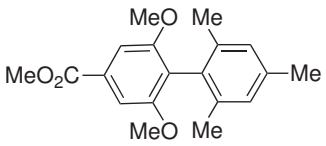
2 **41** **9**



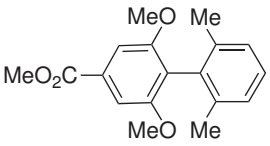
9k: 99%



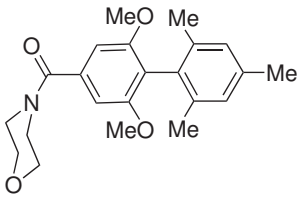
9l: 92%



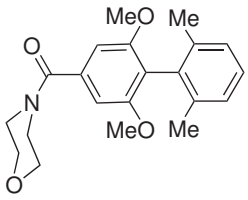
9m: 95%



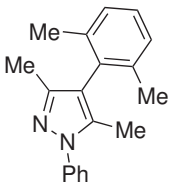
9n: 76%



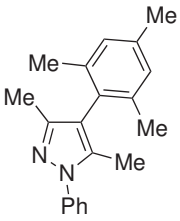
9o: 73%



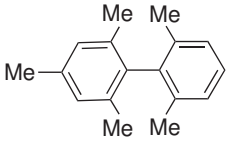
9p: 71%



9q: 90%[b]
46%[c]



9r: 95%[b]
42%[c]

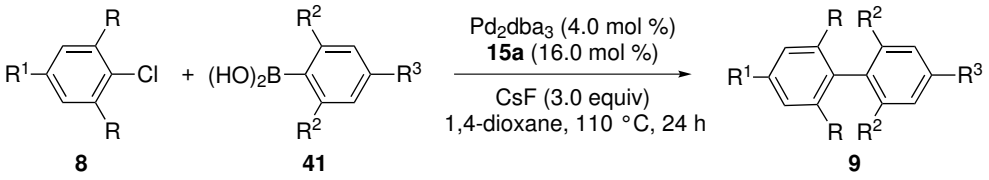


9s: 79%[b]
86%[b,d]

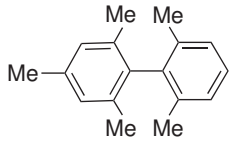
[a] **2** (0.50 mmol), **41** (0.75 mmol), $Pd_2(dba)_3$(2.0 mol %), **15a** (8.0 mol %), CsF (3.0 equiv), 1,4-dioxane (2 mL), 80 °C, 24 h. [b] $Pd_2(dba)_3$(4.0 mol %), **15a** (16.0 mol %). [c] GC-MS conversion. [d] 2,6-dimethylbromobenzene (0.50 mmol), **41c** (0.75 mmol), 24 h.

Intriguingly, the absence of methoxy groups at the *ortho*-position of aryl bromides resulted in lower reactivity, thus demanding the use of higher catalyst loadings (**9q**–**9s**). To my delight, the palladium catalyst derived from diaminochlorophosphine **15a** could also be applied for the challenging arylations with sterically hindered aryl chlorides (Chart 3.3). However, these reactions needed to be performed at higher reaction temperatures and for slightly longer reaction times. Surprisingly, no cross-coupled products were isolated in reactions with *ortho*-methoxy-substituted aryl chlorides. The better reactivity of aryl bromides can be attributed to the more facile oxidative addition of aryl bromides in comparision to the one of the corresponding chlorides.

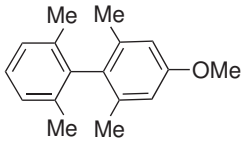
Chart 3.3: Synthesis of tetra-*ortho*-substituted biaryls using aryl chlorides **8**.[a]



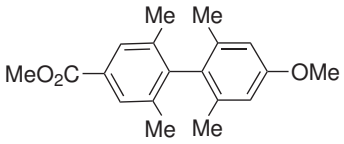
8 **41** **9**



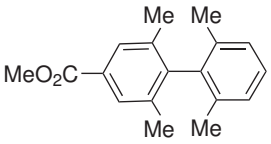
9s: 53%



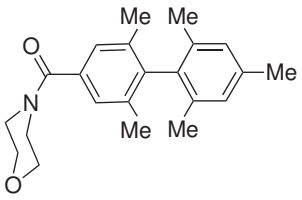
9t: 51%



9u: 53%



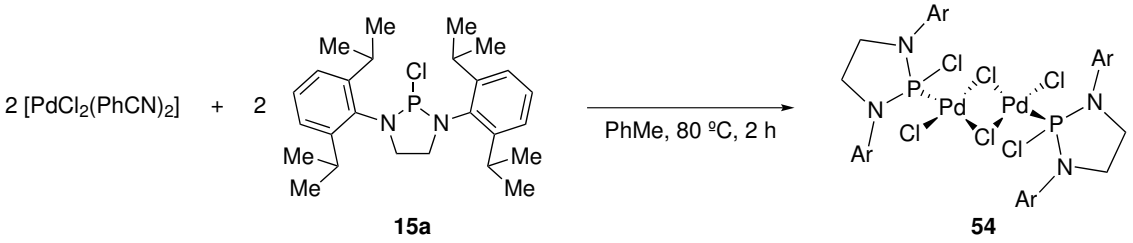
9v: 49%



9w: 57%

[a] **8** (0.50 mmol), **41** (0.75 mmol), $Pd_2(dba)_3$(4.0 mol %), **15a** (16.0 mol %), CsF (3.0 equiv), 1,4-dioxane (2 mL), 110 °C, 24 h.

Concerning the nature of the catalytically active species, it should be mentioned that monophosphine-coordinated palladium(II) complex[82] was formed in the reaction of chlorophosphine **15a** with dichlorobis(acetonitrile)-palladium(II) (Scheme 3.2), which was shown to be catalytically competent.[83,84]



15a **54**

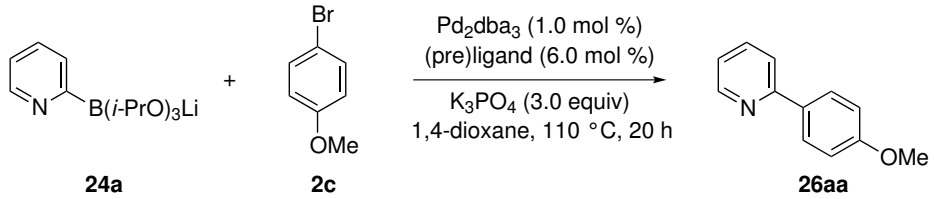
Scheme 3.2: Synthesis of a palldium-complex **54**.

The steric bulk exerted by the substituents on chlorophosphine **15a** is supposed to increase the total strain in the thereof derived palladium species **54**, thus enhancing its catalyst′s efficacy in the formation of tetra-*ortho*-substituted biaryls **9**. Hence, a palladium complex derived from diaminochlorophosphine **15a** enabled the Suzuki-Miyaura cross-coupling for the synthesis of tetra-*ortho*-substituted biaryls.

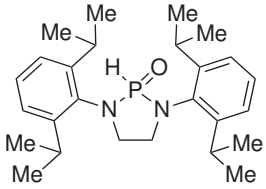
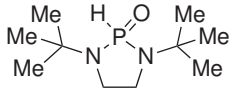
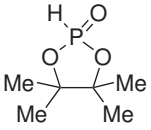
3.1.3 Use of lithium (pyridin-2-yl)borates

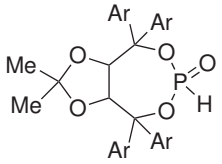
At the outset of my studies, I tested various (pre)ligands in the challenging palladium-catalyzed cross-coupling reaction of borate **24a** with electron-rich aryl bromide **2c**. The use of biaryl monophosphine, such as X-Phos,[15] did not significantly affect the outcome of the reaction (Table 3.3, entry 3). However, more promising results were obtained with sterically hindered diaminophosphine oxide **13a** as preligand (entry 6). A comparable efficacy was observed for palladium complexes derived from either unsubstituted TADDOLP(O)H[85,86] (entry 9) or analogs **14b**[87] and **14c** bearing electron-releasing groups on their arene rings (entries 10–13). Interestingly, the use of HASPO preligand **14d**, which contains electron-deficient aryl-substituents, considerably enhanced the catalytic activity (entry 14). Furthermore, the inorganic base K_3PO_4 provided optimal results (entries 14–15). Importantly, the use of simple trisubstituted phosphites, such as **53**, as additives had no beneficial effect on catalytic performance (entry 4), highlighting the unique reactivity profile of HASPO preligands.

Table 3.3: Evaluation of (pre)ligands for the Suzuki-Miyaura cross-coupling of borate **24a**.[a]



24a **2c** **26aa**

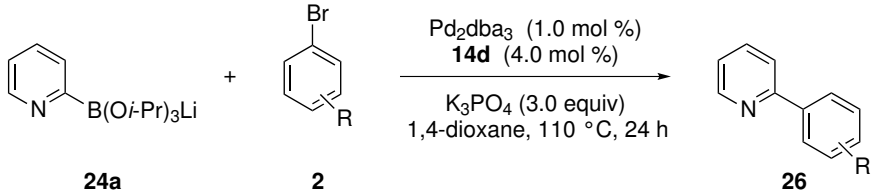
entry	(pre)ligand		base	yield (%)
1	–	–	K_3PO_4	24
2	PPh_3	**50**	K_3PO_4	<5
3	X-Phos	**55**	K_3PO_4	24
4	$P(OPh)_3$	**53**	K_3PO_4	14
5	$(EtO)_2P(O)H$	**52**	K_3PO_4	44
6		**13a**	K_3PO_4	30
7		**13c**	K_3PO_4	24
8		**12**	K_3PO_4	18

9		Ar = Ph **14a**	K_3PO_4	31
10		Ar = 2-MeC_6H_4 **14b**	K_3PO_4	37
11		Ar = 2-MeC_6H_4 **14b**	KF	43
12		Ar = 4-MeC_6H_4 **14c**	K_3PO_4	35
13		Ar = 2-MeC_6H_4 **14b**	KF	31
14		Ar = 4-FC_6H_4 **14d**	K_3PO_4	52
15		Ar = 4-FC_6H_4 **14d**	K_3PO_4	64[b]
16		Ar = 4-FC_6H_4 **14d**	Na_3PO_4	<5
17		Ar = 4-FC_6H_4 **14d**	Et_3N	<5
18		Ar = 4-FC_6H_4 **14d**	KOH	19
19		Ar = 4-FC_6H_4 **14d**	Cs_3CO_3	49
20		Ar = 4-FC_6H_4 **14d**	KF	33

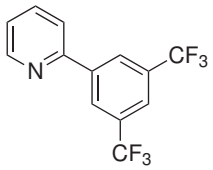
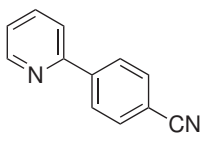
[a] **24a** (0.75 mmol), **2c** (0.50 mmol), $Pd_2(dba)_3$(1.0 mol %), (pre)ligand (6.0 mol%), K_3PO_4 (3.0 equiv), 1,4-dioxane, 110 ℃, 20 h; [b] [Pd] : preligand = 1: 2.

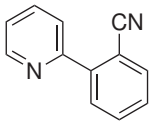
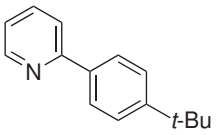
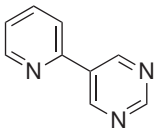
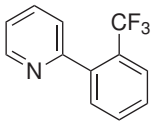
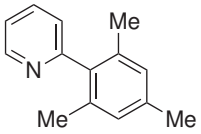
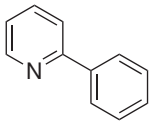
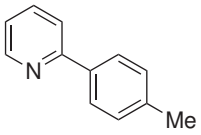
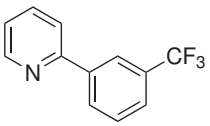
With an optimized catalytic system, I explored its scope in Suzuki–Miyaura cross-coupling reactions between 2-pyridylborate **24a** and various aryl bromides **2** (Table 3.4). Electrophiles with a range of functional groups were converted chemoselectively into the desired products **26ab**–**26aj**. Furthermore, heteroaromatic electrophiles, such as pyrimidyl bromide **2h**, were well tolerated by the catalytic system (entry 5). However, the sterically more demanding coupling partner **2j** led to a lower yield (entry 7) using the preligand **14d**.

Table 3.4: Scope of Suzuki-Miyaura cross-coupling of lithium (pyridin-2-yl)borate **24a**.[a]



24a **2** **26**

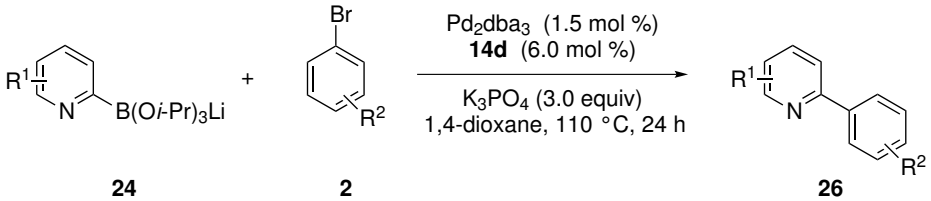
entry	**2**		product		yield (%)
1	3,5-$(CF_3)_2C_6H_3$	**2d**		**26ab**	78
2	4-CNC_6H_4	**2e**		**26ac**	87

3	2-CNC_6H_4	**2f**		**26ad**	80
4	4-(t-Bu)C_6H_4	**2g**		**26ae**	61
5	5-$C_4N_2H_3$	**2h**		**26af**	81
6	2-$CF_3C_6H_4$	**2i**		**26ag**	43
7	2,4,6-$(CH_3)_3C_6H_2$	**2j**		**26ah**	30
8	C_6H_5	**2a**		**9af**	49
9	4-MeC_6H_4	**2k**		**26ai**	65
10	3-$CF_3C_6H_4$	**2l**		**26aj**	69

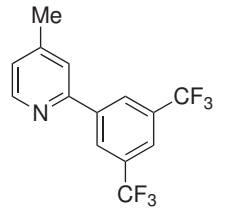
[a] **24a** (0.75 mmol), **2** (0.50 mmol), $Pd_2(dba)_3$(1.0 mol %), **14d** (4.0 mol%), K_3PO_4 (3.0 equiv), 1,4-dioxane (2 mL), 110 °C, 24 h.

The generality of the catalytic system derived from preligand **14d** has been further illustrated by the synthetic utility of substituted nucleophiles **24** (Chart 3.4). A slight increase in the catalyst loading resulted in improved isolated yields (**26ak**–**26am**). Notably, various functionalized aryl bromides **2** could be employed as electrophiles for the cross-coupling reactions with borates **24** (**26ak**–**26ay**). Likewise, heteroaryl bromide **2h** was also found to be a suitable starting material (**26an**, **26as**, and **26ax**). The protocol was not restricted to the use of electron-deficient electrophiles **2**, but also enabled the conversion of the electron-rich aryl bromide **2c** (**26au**, and **26ay**).

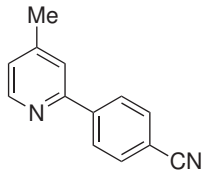
Chart 3.4: Scope of Suzuki-Miyaura coupling with substituted lithium (pyridin-2-yl)borates.[a]



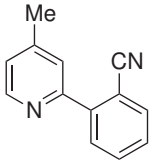
24 **2** **26**



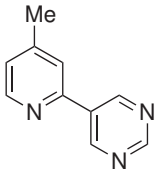
26ak: 67%
66%[b]



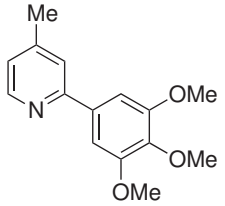
26al: 57%
50%[b]



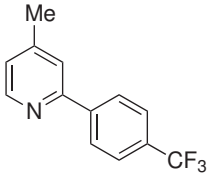
26am: 54%
48%[b]



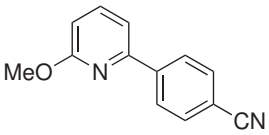
26an: 63%
56%[b]



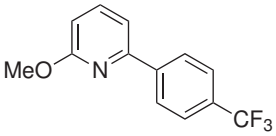
26ao: 22%



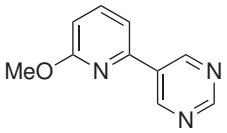
26ap: 71%



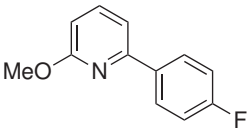
26aq: 64%



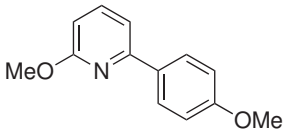
26ar: 68%



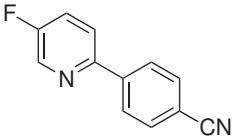
26as: 82%



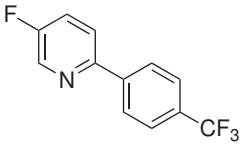
26at: 66%



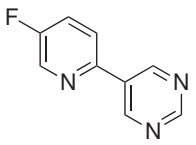
26au: 62%



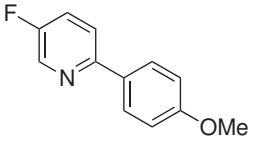
26av: 39%



26aw: 39%



26ax: 35%

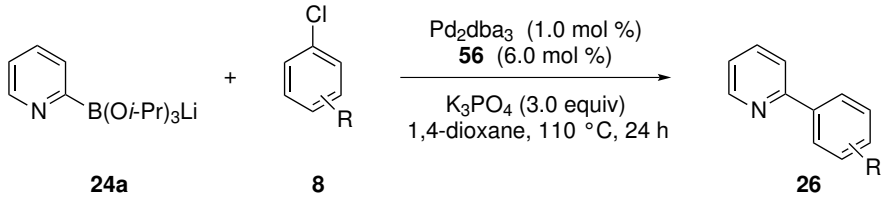


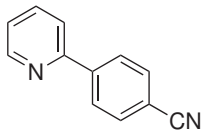
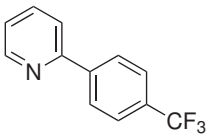
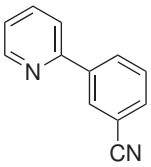
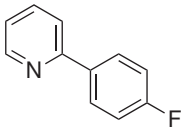
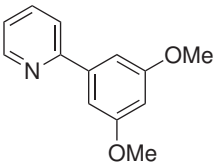
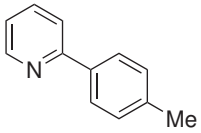
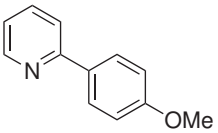
26ay: 41%

[a] **24** (0.75 mmol), **2** (0.50 mmol), $Pd_2(dba)_3$(1.5 mol %), **14d** (6.0 mol %), K_3PO_4 (3.0 equiv), 1,4-dioxane (2 mL), 110 °C, 24 h; [b] $Pd_2(dba)_3$(1.0 mol %), **14d** (4.0 mol %).

The diminished isolated yields in case of fluorine-substituted pyridine nucleophiles (**26av**–**26ay**) can be attributed to the difficulty of the transmetalation step in the catalytic cycle. Additionally, the use of SPO preligand 1-adamantyl phosphine oxide **56** for this transformation allowed the use of less reactive aryl chlorides **8** as well (Table 3.5).

Table 3.5: Suzuki-Miyaura cross-coupling of 2-pyridylborates with arylchlorides.[a]



entry	**8**		product		yield (%)
1	4-CNC_6H_4	**8c**		**26ac**	71
2	4-$CF_3C_6H_4$	**8k**		**26az**	67
3	3-CNC_6H_4	**8l**		**26ba**	67
4	4-FC_6H_4	**8f**		**26bb**	66
5	3,5-$(MeO)_2C_6H_3$	**8m**		**26bc**	72
6	4-MeC_6H_4	**8n**		**26ai**	71
7	4-$MeOC_6H_4$	**8b**		**26aa**	69

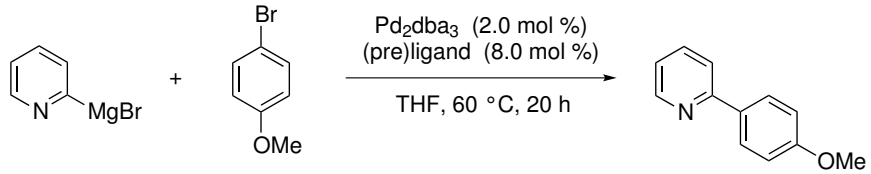
[a] **24a** (0.75 mmol), **8** (0.50 mmol), $Pd_2(dba)_3$(1.0 mol %), **56** (6.0 mol %), K_3PO_4 (3.0 equiv), 1,4-dioxane (2 mL), 110 ℃, 24 h.

Overall, I developed a novel, air-stable electron-deficient TADDOLP(O)H derived HASPO preligand for effective Suzuki–Miyaura cross-coupling reactions of 2-pyridylborates **24**. This protocol is broadly applicable to coupling reactions of these challenging nucleophiles.

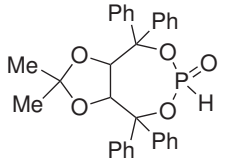
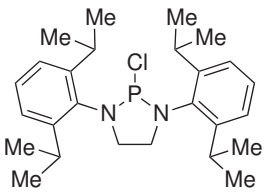
3.2 Kumada-Corriu cross-coupling reactions

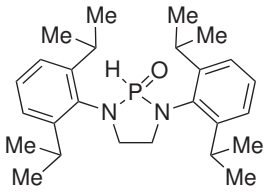
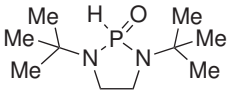
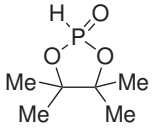
Elegant synthetic applications of 2-pyridylboronates **24** have further inspired efforts towards the cross-coupling of (pyridin-2-yl)magnesium reagents. The starting Grignard reagent **43** was prepared according to the literature procedure[88] utilizing two equivalents of magnesium and stoichiometric amount of dibromomethane. Extensive screening was performed to establish conditions for an unprecedented[74–76] cross-coupling of 2-pyridyl Grignard reagents with aryl bromides (Table 3.6). Unfortunately, monodentate phosphine **55** provided unsatisfactory result (Table 3.6, entry 2). On the contrary, a promising conversion of the starting materials was observed when employing aryl-substituted SPO **57** (entry 8). A catalyst derived from more sterically hindered aryl-substituted preligand **58**, however, proved to be less efficient (entry 9). Interestingly, alkyl-substituted SPO preligands **56** and **28** turned out to be superior (entries 11 and 13), with sterically demanding, non-hygroscopic $(1\text{-Ad})_2\text{P(O)H}$ (**56**)[43,45,89] leading to optimal results (entry 11). Under otherwise identical reaction conditions the use of $[\text{Ni(cod)}_2]$, $[\text{Ni(acac)}_2]$ did not lead to the formation of the desired product.

Table 3.6: Kumada-Corriu cross-coupling with 2-pyridylmagnesium bromide.[a]



43 **2c** **26aa**

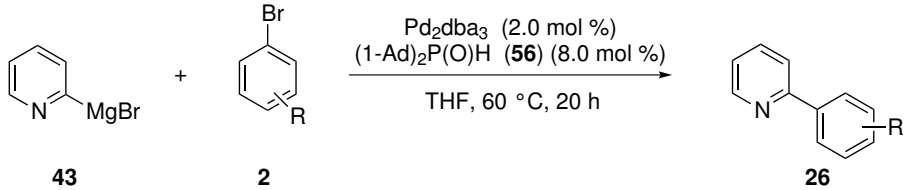
entry	(pre)ligand		yield (%)
1	–		–
2	X-Phos	**55**	–
3		**14a**	–
4		**15a**	–

5		**13a**	26
6		**13c**	4
7		**12**	12
8	$(o\text{-Tol})_2P(O)H$	**57**	25
9	$Mes_2P(O)H$	**58**	8
10	$Ph_2P(O)H$	**27**	25
11	$(1\text{-Ad})_2P(O)H$	**56**	67
12	$(EtO)_2P(O)H$	**52**	-
13	$(t\text{-Bu})_2P(O)H$	**28**	47
14	PEPPSI	**59**	<5
15	Pd(allyl)IPr.Cl	**60**	<5

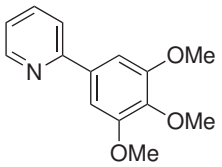
[a] **43** (0.50 mmol), **2c** (0.75 mmol), $Pd_2(dba)_3$(2.0 mol %), (pre)ligand (8.0 mol %), THF (3.0 mL), 60 °C, 20 h. PEPPSI = pyridine-enhanced precatalyst preparation stabilization and initiation.

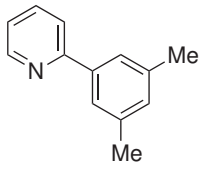
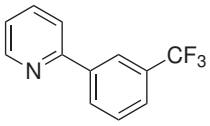
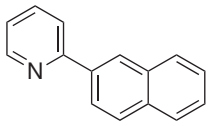
The scope of this methodology was explored in cross-coupling reactions of **43** and aryl bromides **2** utilizing the optimized conditions (Table 3.7). Hence, electrophiles bearing valuable functional groups, such as trifluoromethyl or methoxy, were chemoselectively converted to products **26bd**–**26bf**.

Table 3.7: Scope of Kumada-Corriu cross-coupling with 2-pyridylmagnesium bromide.[a]



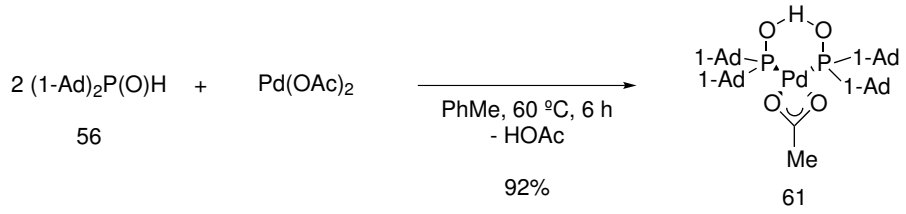
43 **2** **26**

entry	**2**	product	yield (%)
1	$3,4,5\text{-}(MeO)_3C_6H_2$ **2m**	 **26bd**	66

2	3,5-$(Me)_2C_6H_3$	**2n**		**26be**	76
3	3-$(CF_3)C_6H_4$	**2l**		**26aj**	65
4	2-Napthyl	**2o**		**26bf**	93

[a] **43** (1.50 mmol), **2** (1.00 mmol), $Pd_2(dba)_3$(2.0 mol %), **56** (8.0 mol %), THF (3.0 mL), 60 °C, 20 h.

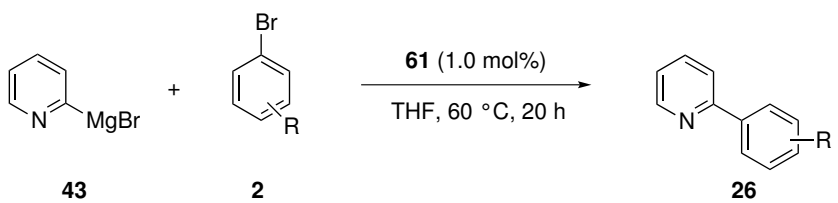
Taking into account the unique reactivity profile of the *in situ* generated complex from SPO **56**, we became interested in exploring its coordination chemistry and working mode. By reacting preligand **56** with $Pd(OAc)_2$, *Dr. Anant Kapdi* successfully obtained a palladium complex **61** bearing a self-assembled bidentate ligand. This transformation occurred even in the absence of an additional external base (Scheme 3.3).

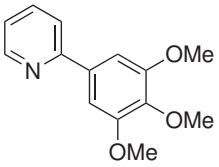
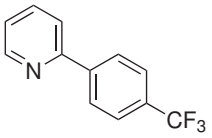
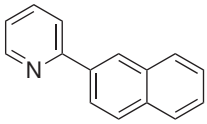
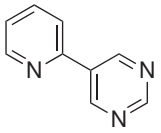
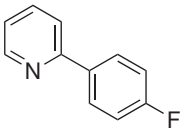
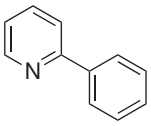


Scheme 3.3: Palladium-complex **61** derived from 1-$Ad_2P(O)H$ (**56**).

Indeed, this isolated, well-defined palladium complex **61** exhibited a remarkably high catalytic activity in the challenging cross-coupling of pyridin-2-yl Grignard reagents **43** (Table 3.8). As a result, a significantly lower catalyst loading turned out to be sufficient for achieving effective cross-coupling reactions. Thereby, Grignard reagent **43** was selectively coupled with aryl bromides **2** bearing useful functionalities.

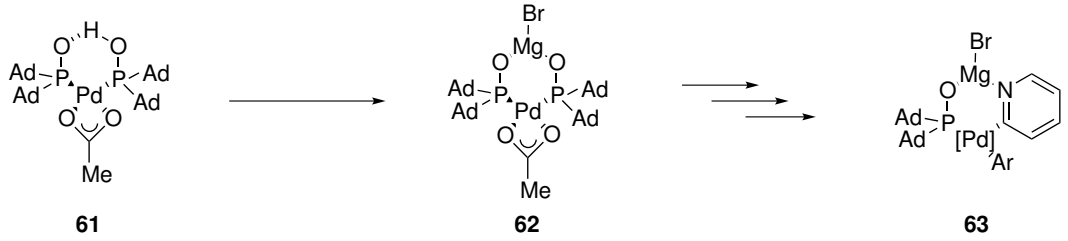
Table 3.8: Scope of Kumada-Corriu cross-coupling using palladium-complex **61**.[a]



entry	**2**		product		yield (%)
1	3,4,5-$(MeO)_3C_6H_2$	**2m**		**26bd**	78
2	4-$CF_3C_6H_3$	**2p**		**26az**	86
3	2-Napthyl	**2o**		**26bf**	93
4	5-$C_4N_2H_3$	**2h**		**26af**	81
5	4-FC_6H_4	**2q**		**26bb**	61
6	C_6H_5	**2a**		**9af**	88

[a] **43** (1.50 mmol), **2** (1.00 mmol), **61** (1.0 mol %), THF (3.0 mL), 60 °C, 20 h.

It is well documented that the stabilizing proton in bidentate complexes derived from secondary phosphine oxides posses high acidic character.[10] I propose that a heterobimetallic structural motif **62** derived from the reaction of palladium complex **61** with basic Grignard reagent **43**[90] enables efficient coupling reactions with challenging 2-pyridyl nucleophiles through the formation of intermediates of type **63** (Scheme 3.4).



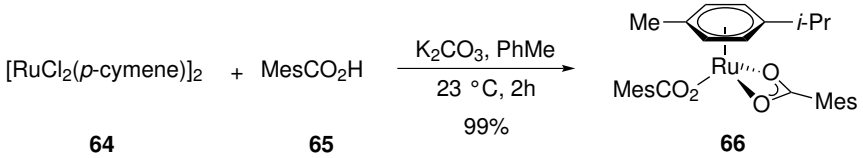
Scheme 3.4: Proposed working mode of the complex **61**.

This protocol represents the most efficient, generally applicable cross-coupling reactions of easily available pyridin-2-yl organomagnesium reagents **43**. A valuable asset of this

methodology is represented by the air- and moisture-stable nature of $(1\text{-Ad})_2\text{P(O)H}$ (**56**), which proved to be superior to commonly used phosphine or carbene ligands.

3.3 Ruthenium-catalyzed direct arylations

Several generally applicable, efficient protocols for ruthenium-catalyzed arylations using aryl chlorides employing air-stable, electron-rich phosphine oxides as preligands were reported by Prof. Ackermann.[31] Also, carboxylic acid assisted ruthenium-catalyzed direct arylations with organic halides were performed in an apolar solvent.[45] Stoichiometric experiments to elucidate the nature of the *in situ* generated catalyst have been performed. Thus, the reaction of $[\text{RuCl}_2(p\text{-cymene})]_2$ (**64**) with acid **65** selectively delivered ruthenium(II) biscarboxylate complex **66** (Scheme 3.5), the catalytic properties of which will be discussed below.

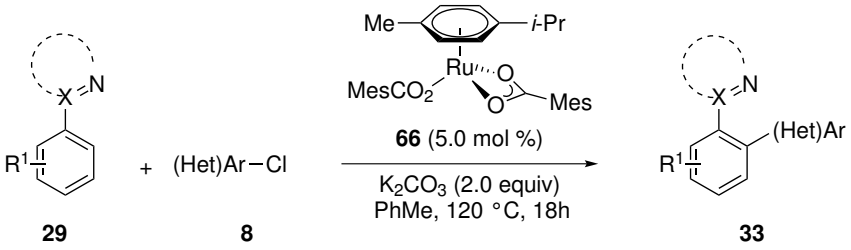


Scheme 3.5: Synthesis of ruthenium-carboxylate complex **66**.

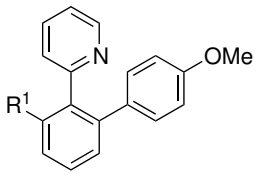
3.3.1 Scope of ruthenium(II)-carboxylate-catalyzed direct arylations

Well-defined ruthenium(II) carboxylate **66** was found to be catalytically competent even in toluene as solvent and displayed a remarkable broad scope in the direct arylations of arenes **29** (Chart 3.5). Thus, various arenes **29** were directly functionalized with differently substituted (hetero)aryl chlorides **8** in a highly regioselective fashion. Generally, transformations with electron-deficient aryl chlorides **8** proceeded more efficiently, and reactions with *meta*-substituted arenes **29** occurred with excellent site-selectivities, providing biphenyls **33aa**–**33au** as the sole products through steric interactions. 2D-NMR experiments clearly established the arylation to occur selectively at C6-position of the arene when *meta*-position is substituted with methyl (**33aq**), methoxy (**33ar**) or trifluoromethyl (**33as**) groups. Notably, an alkene was also selectively arylated (**33av**) to provide the *Z*-isomer using an aryl bromide as the electrophile.

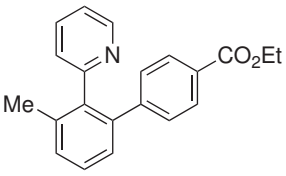
Chart 3.5: Ruthenium-catalyzed direct arylations with well-defined complex **66**.[a]



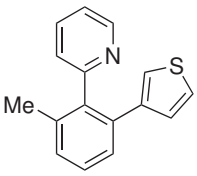
29 **8** **33**



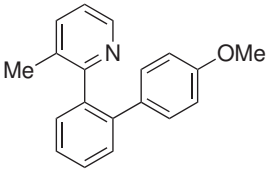
R^1 = Me **(33aa)**: 87%
R^1 = CF_3 **(33ab)**: 94%
R^1 = OMe **(33ac)**: 93%



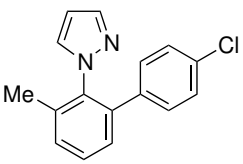
33ad: 98%



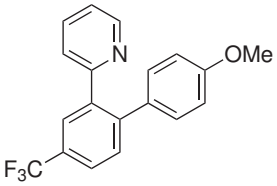
33ae: 82%



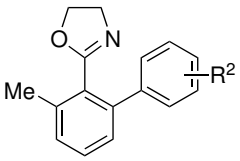
33af: 96%



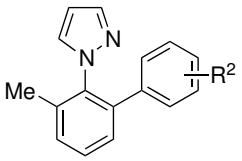
33ao: 98%
(ArBr)



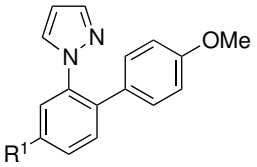
33at: 91%



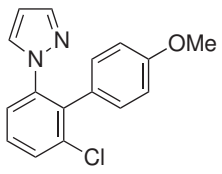
R^2 = 2-OMe **(33ag)**: 53%
R^2 = 4-Me **(33ah)**: 89%
R^2 = 4-CO_2Et **(33ai)**: 94%
R^2 = 4-C(O)Me **(33aj)**: 91%



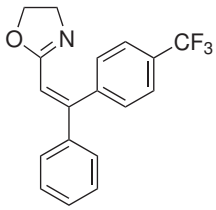
R^2 = 4-OMe **(33ak)**: 98%
R^2 = 2-OMe **(33al)**: 80%
R^2 = 4-CF_3 **(33am)**: 99%
R^2 = 4-CO_2Et **(33an)**: 97%



R^1 = H **(33ap)**: 97%
R^1 = Me **(33aq)**: 98%
R^1 = OMe **(33ar)**: 96%
R^1 = CF_3 **(33as)**: 86%



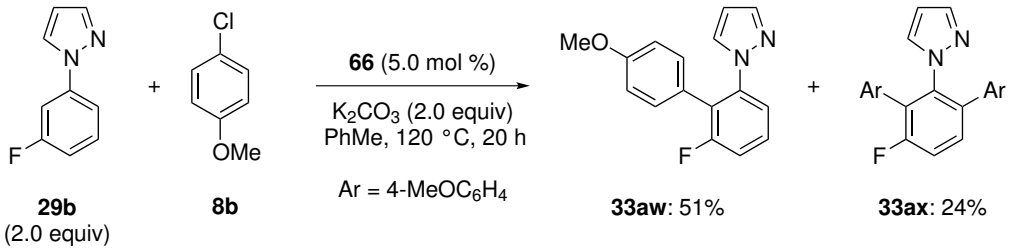
33au: 44%
(ArBr)



33av: 58%
(ArBr)

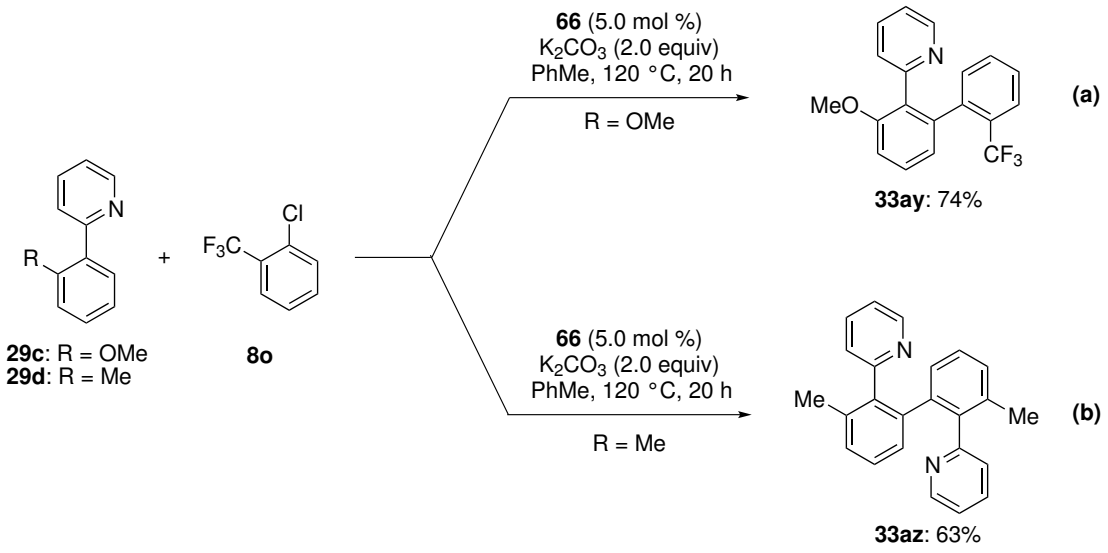
[a] **29** (0.50 mmol), **8** (0.75 mmol), **66** (5.0 mol %), K_2CO_3 (2.0 equiv), PhMe (2.0 mL), 120 °C, 18 h.

An intramolecular competition experiment with 4-chlorobromobenzene demonstrated the preferential reactivity of bromides over chlorides (product **33ao**). Interestingly, arylation of *m*-fluoro-substituted arene **29b** delivered predominantly biphenyl **33aw** (Scheme 3.6) with arylation occuring at the most acidic C–H bond. The bis-arylated product was also obtained in 24% isolated yield. This illustrates the concerted action of the *ortho*-directing influence of the pyrazol-1-yl substitutent along with the well-documented stabilization of metal-carbon bond by *ortho*-neighbouring fluorine atom.[91,92]



Scheme 3.6: Intramolecular competition experiment with *meta*-fluoro-substituted arene.

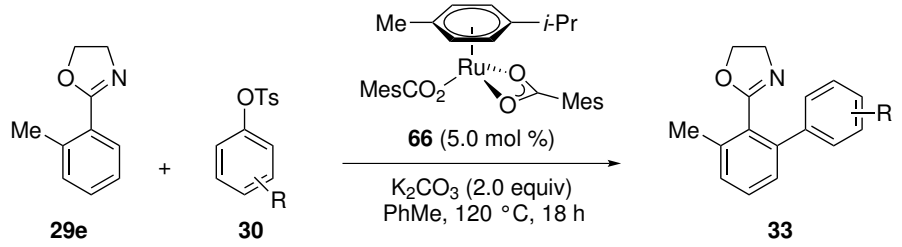
Surprisingly, the reactivity mode of 2-chlorobenzotrifluoride (**8o**) strongly depends on substitution of the nucleophilic arene substrate **29** (Scheme 3.7). While, the reaction of **8o** with 2-*o*-anisyl-pyridine (**29c**) afforded the expected direct arylated product **33ay** (*a*), in the attempted arylation of 2-*o*-tolyl-pyridine (**29d**) with **8o**, oxidatively homo-coupled product **33az** (*b*) was isolated in 63% yield. The chloroarene **8o** served as a formal hydrogen acceptor in this dehydrogenative coupling.[93]

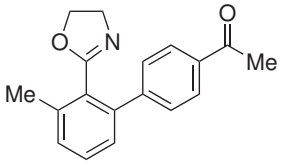


Scheme 3.7: Ruthenium-catalyzed C–H bond functionalizations with **8o**.

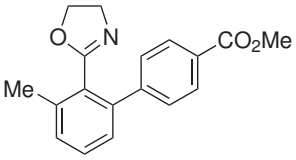
While exploring the scope of these ruthenium-catalyzed direct arylations with different substrates, a number of reactions with tosylates was examined. It was found that 4-acetyl phenyltosylate (**30a**) reacted smoothly with arene **29e** to give the corresponding product **33aj** in 53% isolated yield (Chart 3.6). Similar chemical behaviour was indicated for various aryl tosylates which could thus be successfully employed for this transformation (Chart 3.6).

Chart 3.6: Ruthenium-catalyzed direct arylations with aryl tosylates **30**.[a]

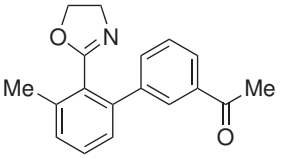




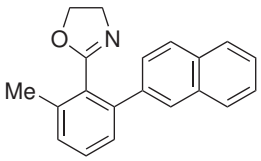
33aj: 53%



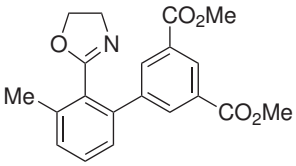
33ba: 58%



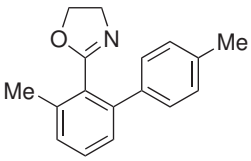
33bb: 86%



33bc: 90%



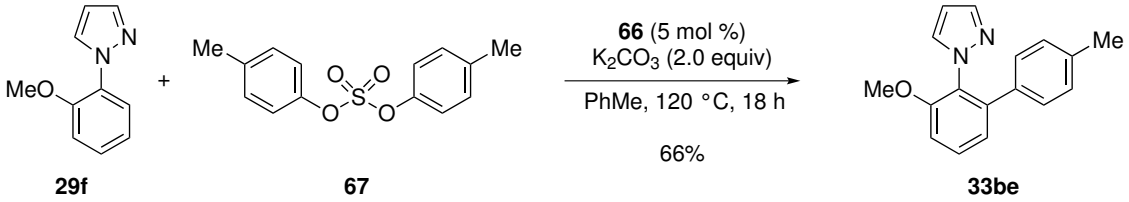
33bd: 81%



33ah: 63%

[a] **29e** (1.00 mmol), **30** (1.20 mmol), **66** (5.0 mol %), K_2CO_3 (2.0 equiv), PhMe (2.0 mL), 120 ℃, 18 h.

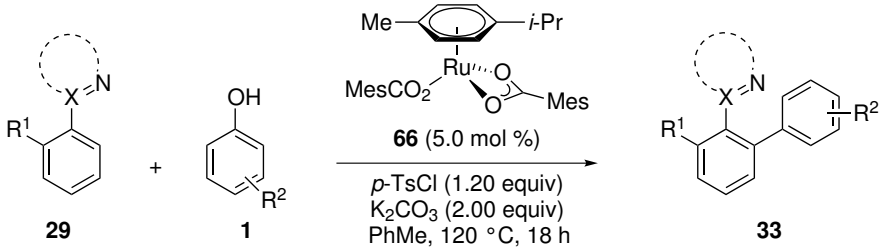
While aryl tosylates and mesylates have been successfully used in direct arylations,[94] diarylsulfates have never been employed for this purpose. Similar to the tosylates and mesylates, these diarylsulfates are also very stable, generally non-toxic and can be stored on bench-top for a long time. In principle, these diarylsulfates can be used as sequential organoelectrophiles in traditional cross-coupling reactions with both the aryl substituents being preferentially used for arylation, making this reaction highly atom-economical.[95] Under catalysis with complex **66**, however, the unprecedented direct arylation of excess of **29f** with di(*p*-tolyl)sulfate **67** furnished the desired product **33be** in 66% isolated yield with respect to **67** (Scheme 3.8).

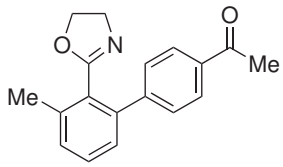


Scheme 3.8: Direct arylation with di(*p*-tolyl)tosylate.

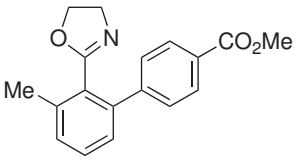
A significantly more sustainable approach would be represented by direct arylations with phenols as pro-electrophilic arylating reagents *via* simultaneous functionalizations of C–H and C–OH bonds. Ackermann *et.al.* reported the first example of efficient, operationally simple, ruthenium-catalyzed dehydrative coupling between simple arenes and inexpensive phenols.[46] Further progress could be achieved with isolated complex **66** for these transformations. It was indicated that the isolated ruthenium(II) biscarboxylate complex **66** appears to be highly active in this ecologically benign methodology (Chart 3.7).

Chart 3.7: Ruthenium-catalyzed direct arylations with phenols.[a]

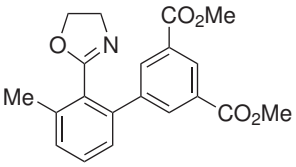




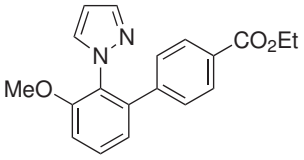
33aj: 68%



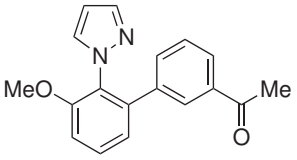
33ba: 61%



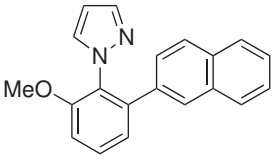
33bd: 77%



33bf: 68%



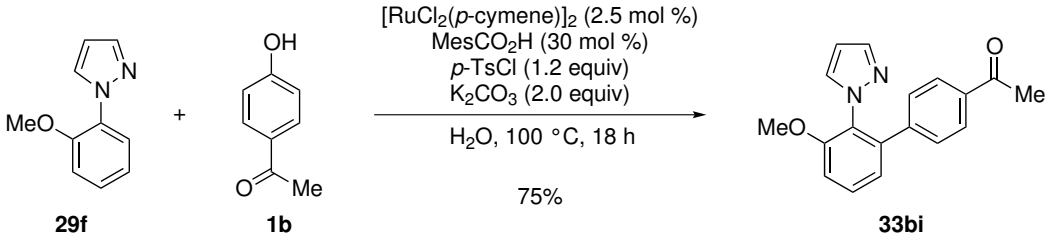
33bg: 79%



33bh: 83%

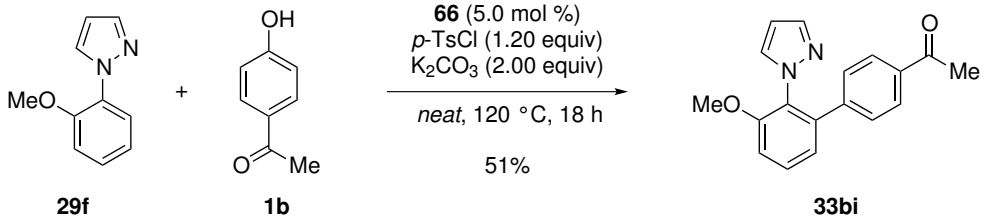
[a] **1** (1.20 mmol), **29** (1.00 mmol), **66** (5.0 mol %), K_2CO_3 (2.0 equiv), PhMe (3.0 mL), 120 °C, 18 h.

The outstanding stability and chemoselectivity of the ruthenium catalyst **64** was highlighted by formal dehydrative arylation of arene **29f** with phenol **1b** on water and even without the preformation of the complex **66**. This reaction represents the unprecedented example of dehydrative direct arylation on water (Scheme 3.9).



Scheme 3.9: Dehydrative direct arylations on water.

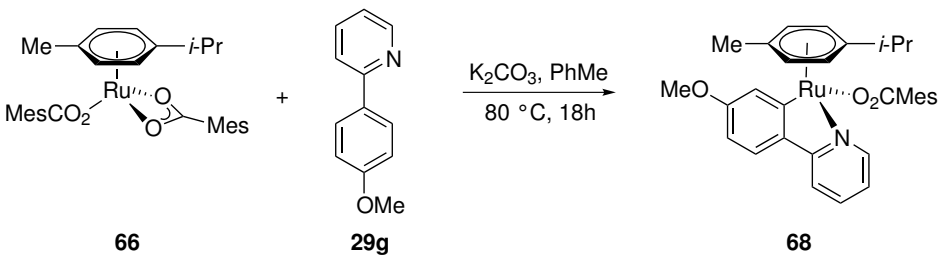
Moreover, the formal dehydrative C–H bond arylation could also be performed *neat*, *i.e.* without any organic solvent, albeit in a somewhat lower yield (Scheme 3.10).



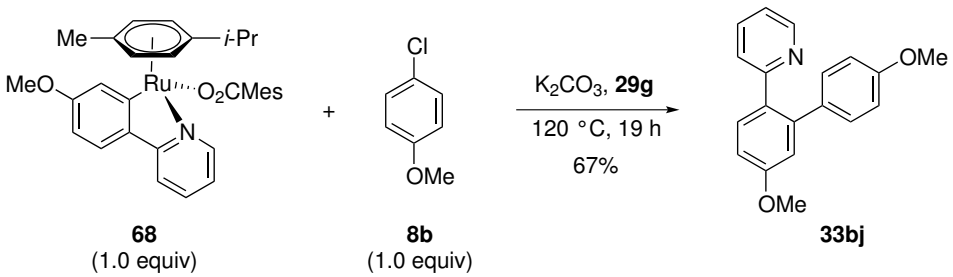
Scheme 3.10: Ruthenium-cataylzed formal dehydrative arylation performed without solvent.

3.3.2 Mechanistic insight into ruthenium-catalyzed direct arylations

Mechanistic studies on catalytic reactions are typically complicated by the complexity of the multistep reactions involved in the overall process. The origin of complexity mainly resides in the various states that a catalytic species may exist, either within the catalytic cycle or as a resting state. To simply matters, mechanistic investigations on a catalytic process are typically accompanied by the corresponding studies on the stoichiometric reactions that are thought to pertain to the catalytic cycle. According to this, the remarkable reactivity profile of complex **66** was initially probed through stoichiometric experiments (Scheme 3.11). Cyclometalation of arene **29g** occurred readily, thereby yielding catalytically competent cyclometalated complex **68** which upon reaction with 4-chloroanisole, yielded the desired product **33bj** (Scheme 3.12).

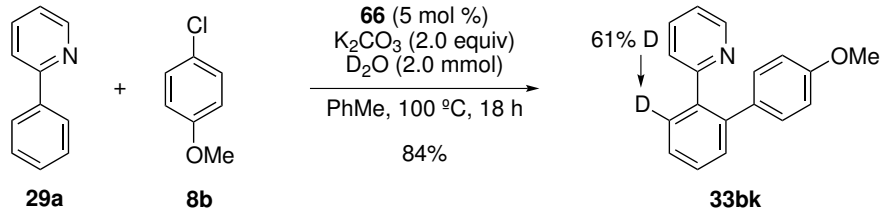


Scheme 3.11: Synthesis of cyclometalated complex **68**.



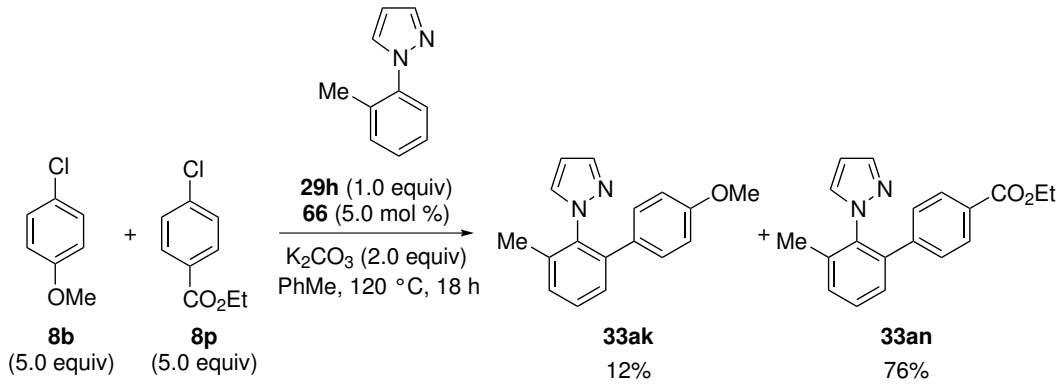
Scheme 3.12: Stoichiometric reaction with cyclometalated complex **68**.

Notably, deuterium labeling studies clearly revealed a D/H-exchange reaction (Scheme 3.13).[96–98]



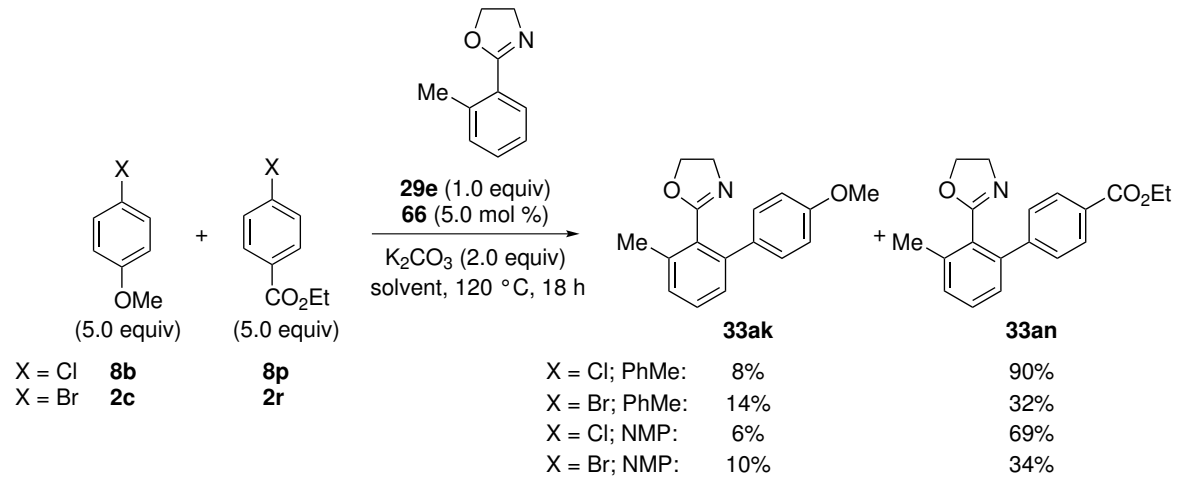
Scheme 3.13: Direct arylation in the presence of D_2O.

In an intermolecular competition experiment with an excess of differently substituted electrophiles **8b** and **8p** (Scheme 3.14), direct arylation occured preferentially with more electron-deficient ethyl-4-chlorobenzoate (**8p**) giving the corresponding product **33an** in 76% isolated yield.



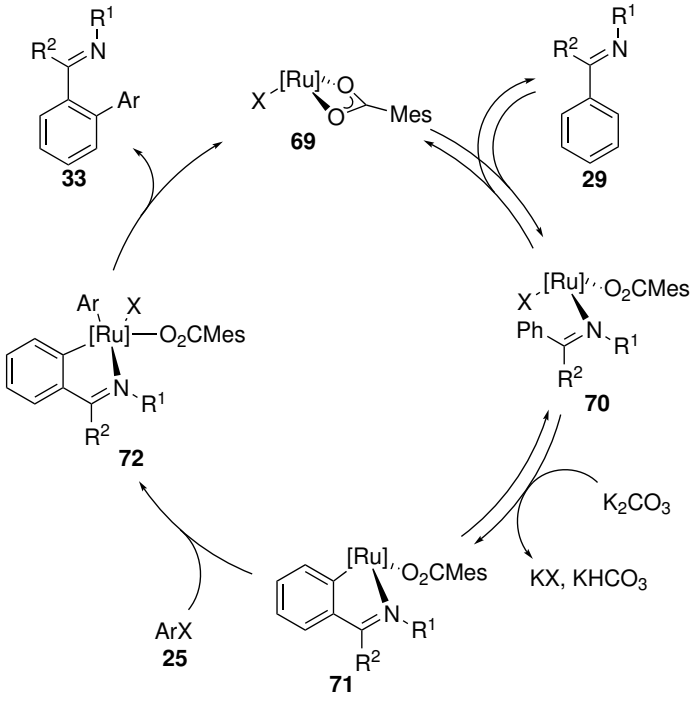
Scheme 3.14: Competition experiment with electrophiles **8b** and **8p**.

This experimental result was also confirmed in additional competition experiments of aryloxazoline **29e** with aryl halides **8b** and **8p**. These transformations showed that electron-deficient aryl halides **8p** and **2r** reacted preferentially (Scheme 3.15). The chemoselectivity was independent of the nature of the leaving group or solvent, and optimal isolated yields were obtained in toluene as the solvent.



Scheme 3.15: Competition experiments with different electrophiles.

On the basis of these experimental studies I propose that complex **69** initially undergoes a reversible cyclometalation through a carboxylate-assisted deprotonation (Scheme 3.16). Thereafter, ruthenacycle **71** undergoes a formal oxidative addition with the aryl halide **25** in the rate-limiting step to yield intermediate **72**. Finally, reductive elimination gives rise to functionalized arenes **33**, and thereby regenerates catalyst **69**.



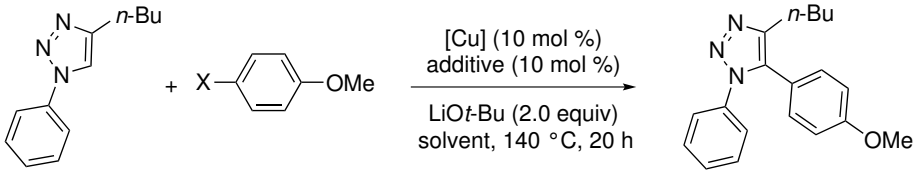
Scheme 3.16: Proposed mechanism for ruthenium-catalyzed direct arylations

3.4 Copper-catalyzed modular synthesis of fully substituted 1,2,3-triazoles

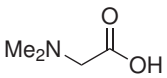
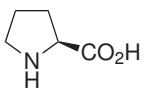
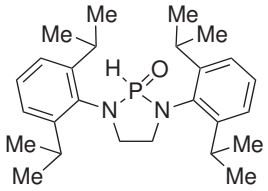
3.4.1 Copper-catalyzed direct arylations of 1,2,3-triazoles

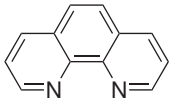
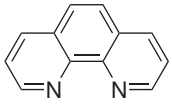
To probe the viability of the envisioned sequential catalytic protocol (Scheme 2.5), the copper-catalyzed direct arylations of 1,4-disubstituted 1,2,3-triazoles **37c** (Table 3.9) through C–H bond cleavages has been tested initially. This transformation could be accomplished with aryl iodides as arylating reagents, provided LiO*t*-Bu served as the base. Interestingly, no ligand-effect was observed, while other milder bases proved ineffective.

Table 3.9: Screening of additives for the copper-catalyzed direct arylation of triazole **37c**[a]



37c **25** **40a**

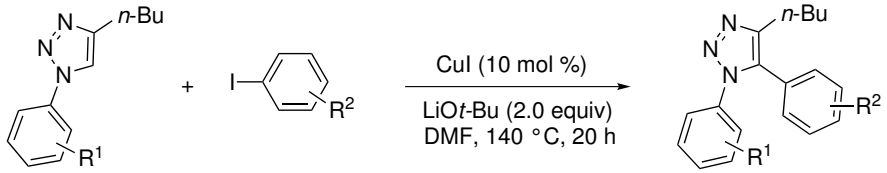
entry	X	[Cu]	ligand/additive		yield (%)
1	I	Cu	-		<5
2[b]	I	Cu	I_2		5
3[c]	I	CuI	-		<5
4	I	CuI	-		70
5[b]	Br	CuI	-		9
6[b]	Br	CuI	PPh_3	**50**	13
7	Br	CuI		**73**	<5
8[b]	Br	CuI		**74**	8
9	Br	CuI		**75**	<5
10	Br	CuI		**13a**	9

11	Br	CuI		**76**	<5
12[d]	Br	CuI		**76**	<5

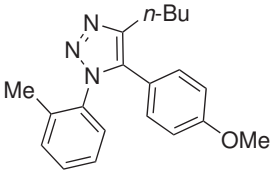
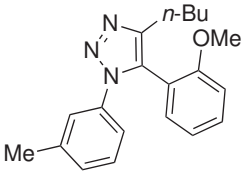
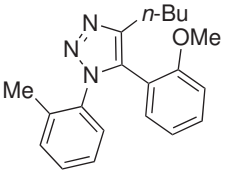
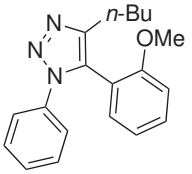
[a] **37c** (1.00 mmol), **25** (3.00 mmol), [Cu] (10 mol %), additive (10 mol %), LiO*t*-Bu (2.0 equiv), DMF (3.0 mL), 140 °C, 20 h. [b] GC-conversion. [c] 1,3-Propanediol as the solvent. [d] K_3PO_4 as the base.

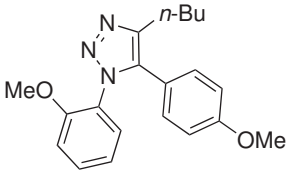
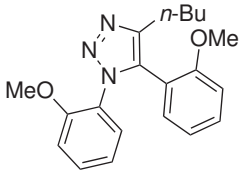
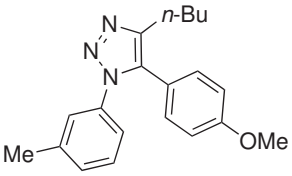
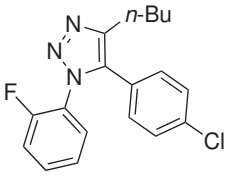
Thus, *N*-aryl substituted triazoles **37** were efficiently arylated with a variety of substituted aryl iodides **77** (Table 3.10). Even *ortho*-fluoro substituted *N*-aryl-1,2,3-triazole **37g** was regioselectively functionalized at the electron-rich triazole moiety (entry 8).

Table 3.10: Copper-catalyzed direct arylation of *N*-aryl substituted triazoles **37**[a]



37 **77** **40**

entry	R^1		R^2				yield (%)
1	2-Me	**37d**	4-MeO	**77a**		**40b**	70
2	3-Me	**37e**	2-MeO	**77b**		**40c**	92
3	2-Me	**37d**	2-MeO	**77b**		**40d**	76
4	H	**37c**	2-MeO	**77b**		**40e**	80

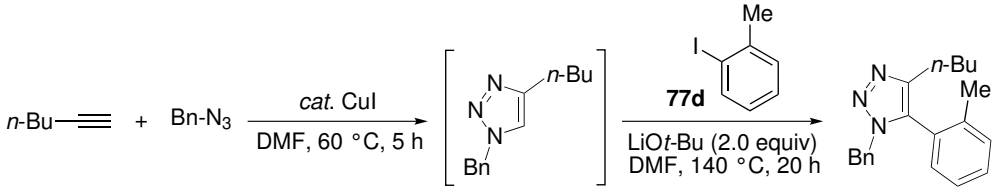
5	2-MeO	**37f**	4-MeO	**77a**		**40f**	65
6	2-MeO	**37f**	2-MeO	**77b**		**40g**	68
7	3-Me	**37e**	4-MeO	**77a**		**40h**	84
8	2-F	**37g**	4-Cl	**77c**		**40i**	42

[a] **37** (1.00 mmol), **77** (3.00 mmol), CuI (10 mol %), LiO*t*-Bu (2.0 equiv), DMF (3.0 mL), 140 °C, 20 h.

3.4.2 Sequential synthesis of fully substituted 1,2,3-triazoles

The above discussed efficient protocol for copper-catalyzed direct arylations of triazoles **37** was applied towards the one-pot sequential synthesis of fully substituted triazoles **40**. At the outset, the preformed alkyl-substituted azides have been chosen as starting materials for the initial catalytic 1,3-dipolar cycloaddition reaction (Table 3.11).

Table 3.11: Development of a sequential synthesis of fully substituted 1,2,3-triazoles.

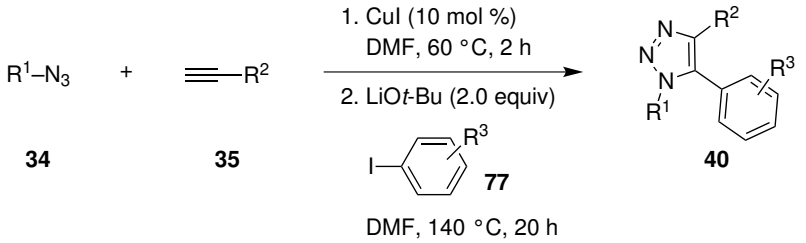


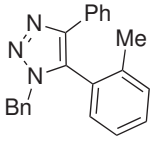
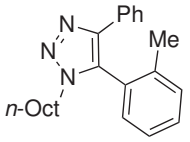
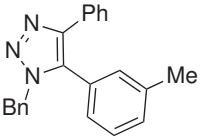
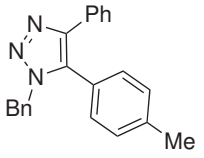
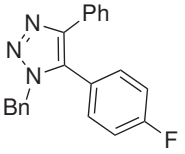
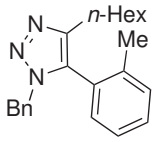
35c **34b** **37h** **40j**

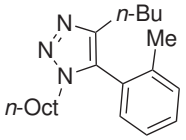
entry	CuI (mol%)	isolated yield (%)
1	30	81
2	20	72
3	10	67

Importantly, these studies revealed that a single inexpensive copper catalyst could be employed for two mechanistically distinct reactions, namely 1,3-dipolar cycloadditions and direct arylation reactions (Table 3.12). This protocol proved broadly applicable, allowing for the use of alkyl- (entries 6 and 7) as well as aryl-substituted alkynes (entries 1–5). Further, electrophiles with either electron-donating or electron-withdrawing (entry 5) substituents were successfully converted, even when using more sterically demanding (entries 1, 2, 6 and 7) aryl iodides.

Table 3.12: Sequential copper-catalyzed synthesis of triazoles **40**[a]



entry	R^1	R^2	R^3	product		yield (%)
1	Bn **34b**	Ph **35a**	2-Me **77d**		**40k**	70
2	*n*-Oct **34c**	Ph **35a**	2-Me **77d**		**40l**	69
3	Bn **34b**	Ph **35a**	3-Me **77e**		**40m**	61
4	Bn **34b**	Ph **35a**	4-Me **77f**		**40n**	55
5	Bn **34b**	Ph **35a**	4-F **77g**		**40o**	40
6	Bn **34b**	*n*-Hex **35d**	2-Me **77d**		**40p**	60

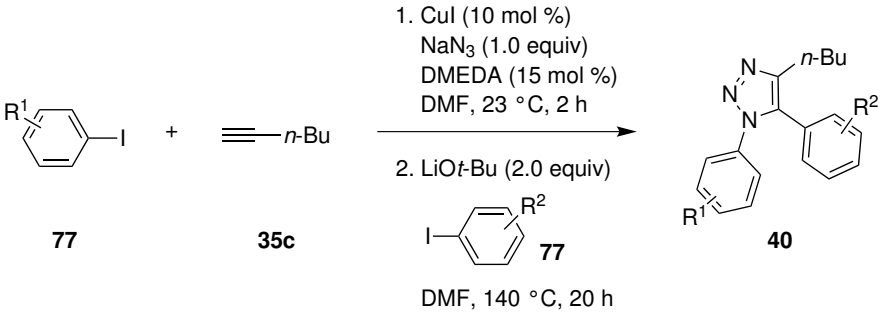
7[b]	*n*-Oct **34c**	*n*-Bu **35c**	2-Me **77d**			**40q**	75

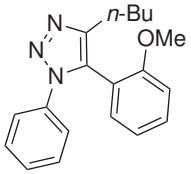
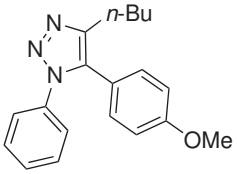
[a] **34** (1.00 mmol), **35** (1.00 mmol), CuI (10 mol %), **77** (3.00 mmol), LiO*t*-Bu (2.0 equiv), DMF (3.0 mL), 140 °C, 20 h. [b] CuI (30.0 mol %).

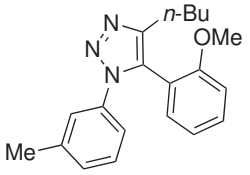
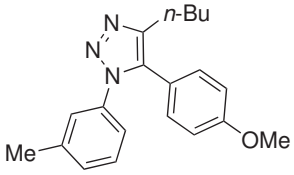
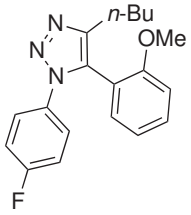
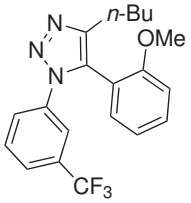
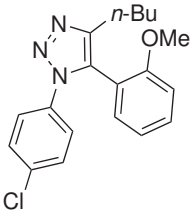
3.4.3 Copper-catalyzed four component synthesis

As a further step towards increasing the versatility of the dipolar cycloaddition/direct arylation approach, a four-component one-pot protocol in which an azide was formed *in situ* from sodium azide was elaborated. While simple CuI served as catalyst for the preparation of *N*-alkyl-substituted 1,2,3-triazoles, the synthesis of the corresponding *N*-aryl analogues required the use of DMEDA as stabilizing ligand for the initial formation of aryl azides from NaN_3 and aryl iodides **77** (Table 3.13). Thereby, a variety of triazoles **40** were obtained, displaying both electron-rich (entries 1–4) as well as functionalized electron-deficient (entries 5–7) aryl-substituents.

Table 3.13: Sequential copper-catalyzed four-component synthesis[a]



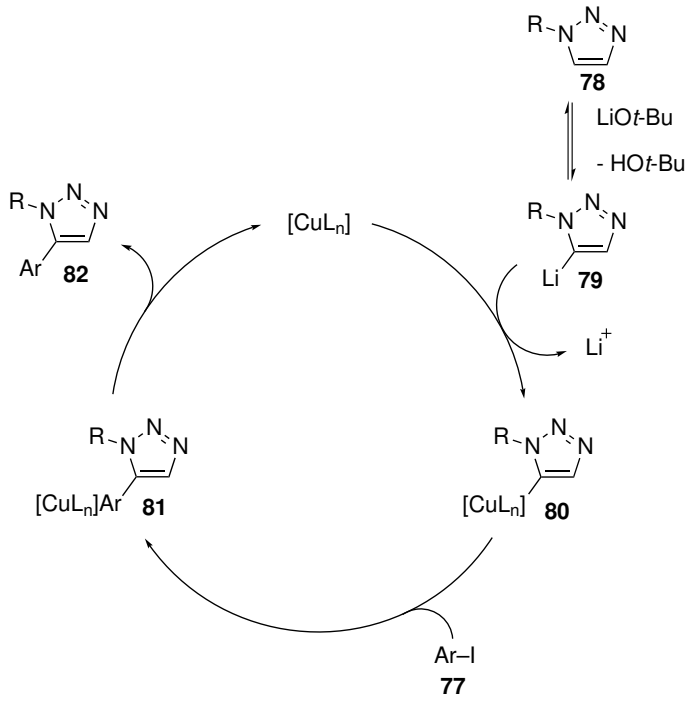
entry	R^1		R^2		product	yield (%)
1	H	**77h**	2-MeO	**77b**		**40e**	74
2	H	**77h**	4-MeO	**77a**		**40a**	73

3	3-Me	**77e**	2-MeO	**77b**		**40c**	81
4	3-Me	**77e**	4-MeO	**77a**		**40h**	70
5	4-F	**77g**	2-MeO	**77b**		**40r**	70
6	3-CF_3	**77i**	2-MeO	**77b**		**40s**	38
7	4-Cl	**77j**	2-MeO	**77b**		**40t**	67

[a] **77** (1.00 mmol), **35c** (1.00 mmol), NaN_3 (1.05 mmol), CuI (10 mol %), DMEDA (15 mol %), **77** (3.00 mmol), LiO*t*-Bu (2.0 equiv), DMF (3.0 mL), 140 °C, 20 h

A probable working mode for these copper-catalyzed direct arylations consists of (i) initial *in situ* deprotonation with the base LiO*t*-Bu, (ii) lithium-copper transmetalation, (iii) activation of the aryl iodide **77** and (iv) final reductive elimination (Scheme 3.17). [60,64] According to this deprotonation-based mechanism, the regioselectivity of the overall transformation of 4,5-unsubstituted triazoles is governed by C–H bond acidity.

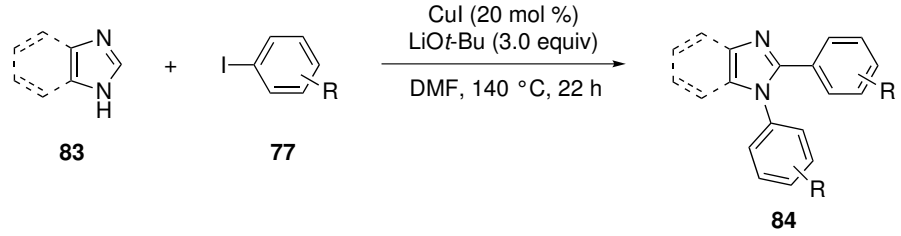
The reaction conditions mentioned above are in general applicable for direct arylations of C–H bonds in *N*-alkylated/arylated heterocycles with $pK_a<35$. [60] However, the success in the sequential synthesis of fully substituted triazoles **40** demonstrates that this catalytic system can probably be employed in a one-pot sequential *N*- and C-arylations of such heterocycles. Indeed, benzimidazole reacted smoothly with 4-iodoanisole (**77a**) to afford diarylated product in 59% isolated yield. However, lowering the reaction temperature resulted in reduced yields of the desired product. Subsequently, a variety of iodoarenes

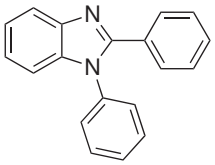
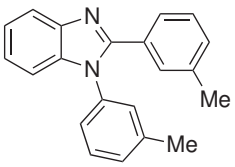


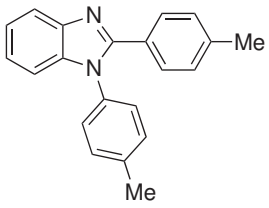
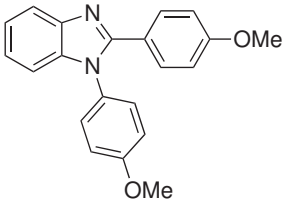
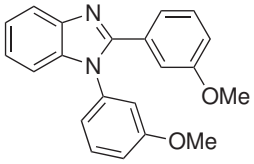
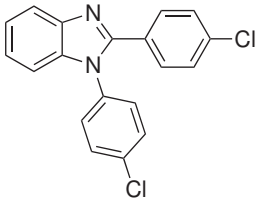
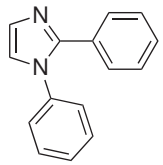
Scheme 3.17: Proposed mechanism for copper-catalyzed direct arylations of 1,2,3-triazoles **37**.

77 were tried for this transformation (Table 3.14), and even imidazole (**85**) could be diarylated, albeit in lower yield (entry 7).

Table 3.14: Copper-catalyzed C–C and C–N bond formation on (benz)imidazoles[a]



entry	R		product		yield (%)
1	H	**77h**		**84a**	77
2	3-Me	**77e**		**84b**	82

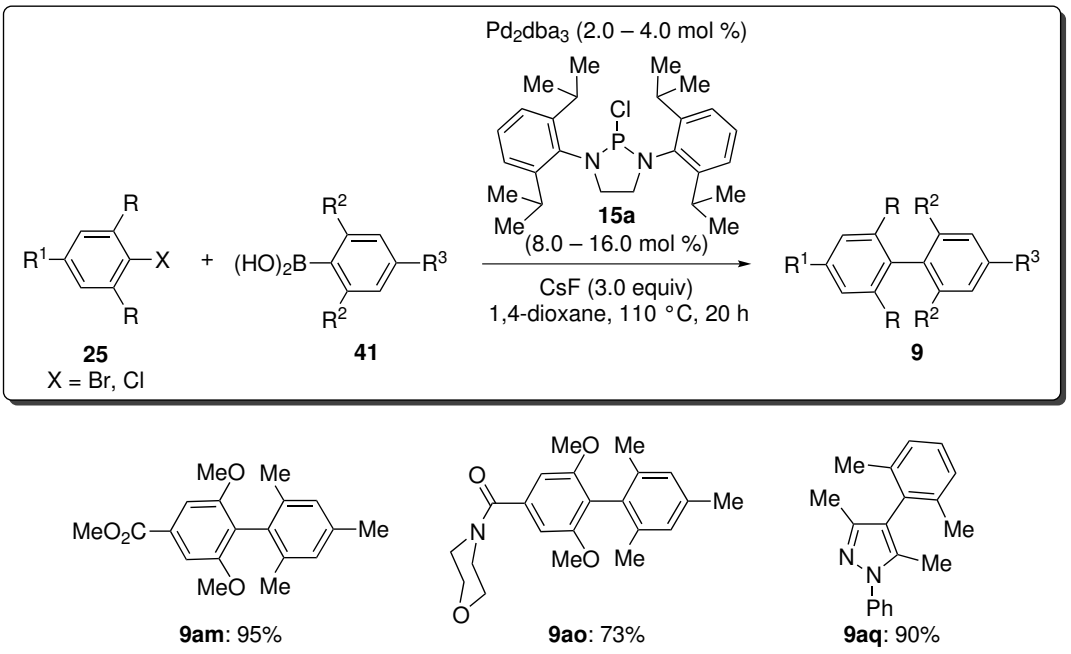
3	4-Me	**77f**		**84c**	83
4	4-MeO	**77a**		**84d**	59
5	3-MeO	**77k**		**84e**	42
6	4-Cl	**77j**		**84f**	62
7	H	**77h**		**84g**	43

[a] **83** (1.00 mmol), **77** (5.00 mmol), CuI (20 mol %), LiO*t*-Bu (3.0 equiv), DMF (3.0 mL), 140 °C, 20 h.

In conclusion, an elaborated copper-catalyzed direct arylation of 1,4-disubstituted triazoles **37** set the stage for the development of a modular one-pot approach to substituted 1,2,3-triazoles **40**. The unprecedented direct arylation-based sequential copper-catalysis combined atom-economical 1,3-dipolar cycloaddition reactions with sustainable C–H-bond functionalizations, thereby enabling the chemoselective coupling of up to four components through the formation of one C–C- and three C–N bonds.

4 Summary and Outlook

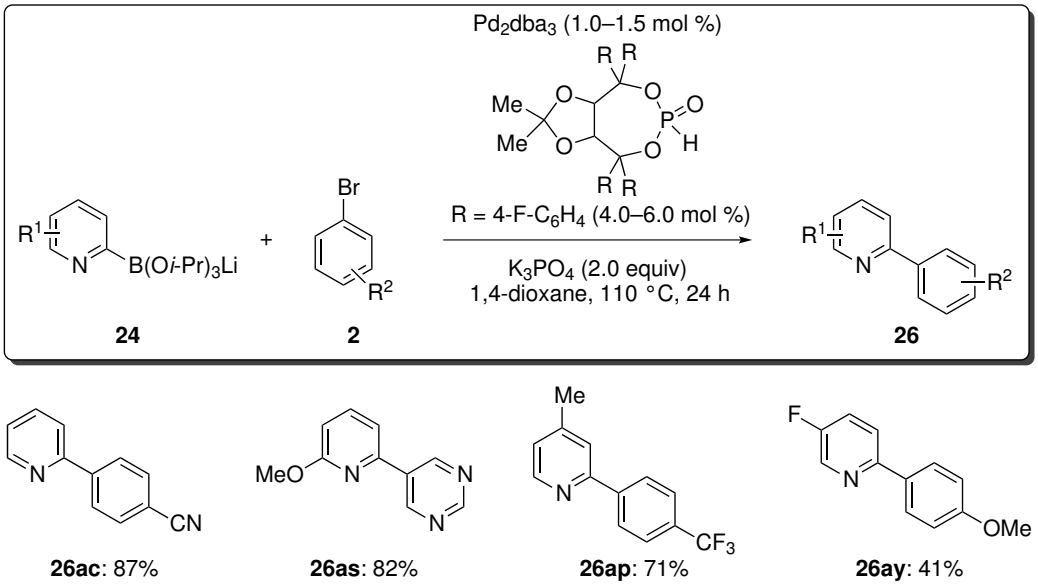
The focus of the doctoral studies was on the development of challenging transition-metal-catalyzed arylations. In the first part, efforts were directed towards the use of palladium complexes derived from air-stable *h*etero-*a*tom *s*ubstituted *p*hosphines *o*xides (HASPO) and chlorides for efficient Suzuki-Miyaura cross-coupling reactions. A palladium complex derived from diaminochlorophosphine **15a** enabled the synthesis of sterically hindered tetra-*ortho*-substituted (hetero)biaryls (Scheme 4.1). Applications of this methodology as well as studies to enable an asymmetric coupling for the enantioselective synthesis of axially chiral biaryls would be challening.



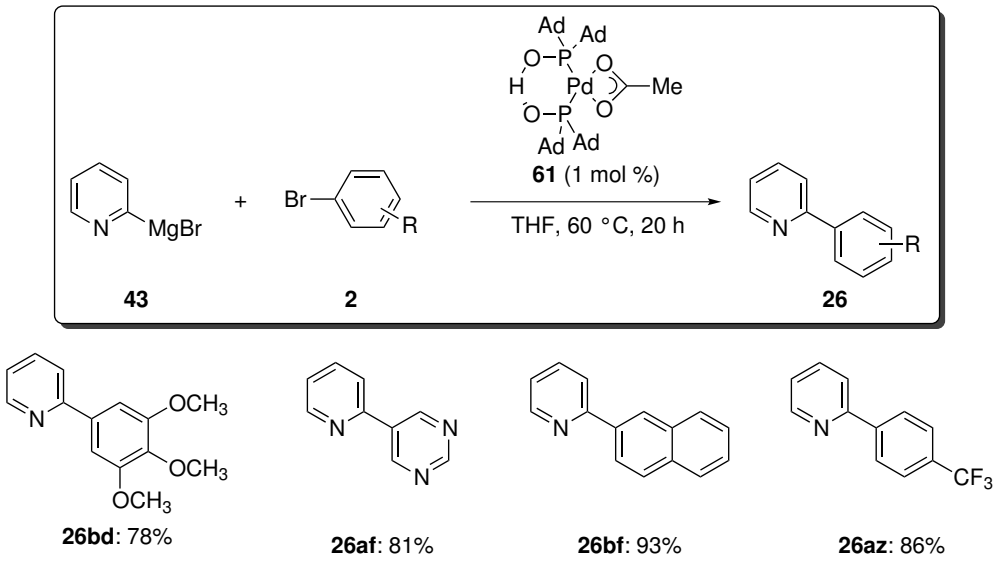
Scheme 4.1: Diaminochlorophosphine **15a** as ligand in palladium-catalyzed Suzuki-Miayura cross-coupling: synthesis of tetra-*ortho*-substituted biaryls.

The scope for Suzuki-Miyuara cross-coupling of challenging 2-pyridylborates through the use of the novel HASPO preligand **14d** (Scheme 4.2) was investigated.

A versatile protocol for cross-coupling reactions of 2-pyridyl organomagnesium compounds was accomplished through the use of a palladium catalysts derived from secondary phosphine oxide $(1\text{-Ad})_2\text{P(O)H}$ (**56**) (Scheme 4.3). Thereby, it was possible to establish an easy access to 2-arylpyridines, which served as substrates for the subsequent direct arylation reactions.



Scheme 4.2: Cross-coupling reactions of lithium (pyridin-2-yl)borates.

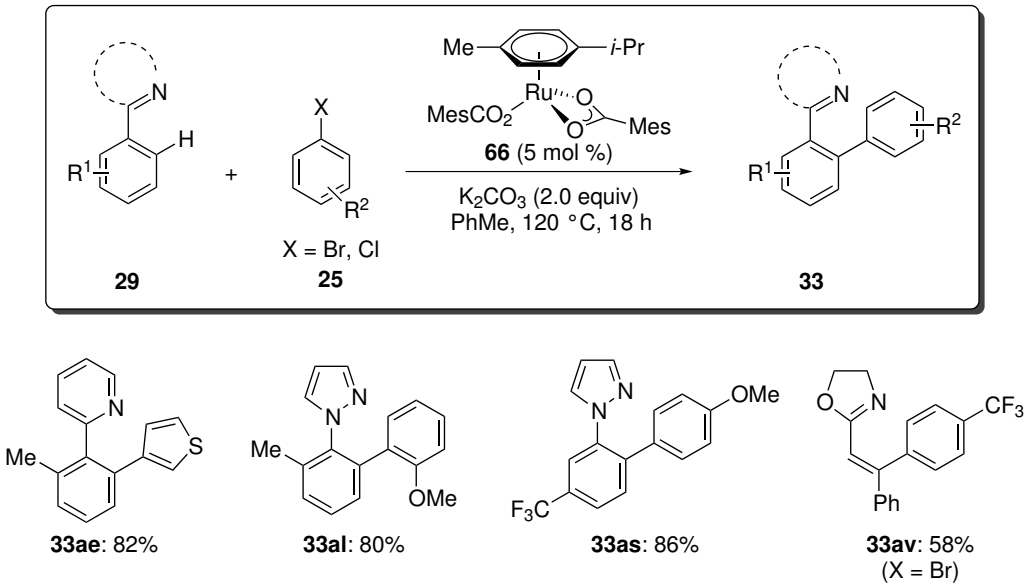


Scheme 4.3: Unprecedented palladium-catalyzed cross-coupling of pyridin-2-yl Grignard reagents.

The aforementioned coupling reactions benefited greatly from the presence of HASPO preligands. These methods allow smooth cross-couplings of challenging pyridin-2-yl nucleophiles which were not possible due to the instability of starting materials as well as their inherent low reactivities. As an extension of these methods, arylations of other classes of pyridin-2-yl nucleophiles should be possible.

Transition metal-catalyzed direct arylation reactions *via* cleavages of C–H bond constitute an economically and ecologically benign alternative to conventional cross-coupling reactions. Efforts were directed towards understanding the mechanism of ruthenium(II)-catalyzed direct arylations. Mechanistic studies revealed ruthenium-catalyzed direct ary-

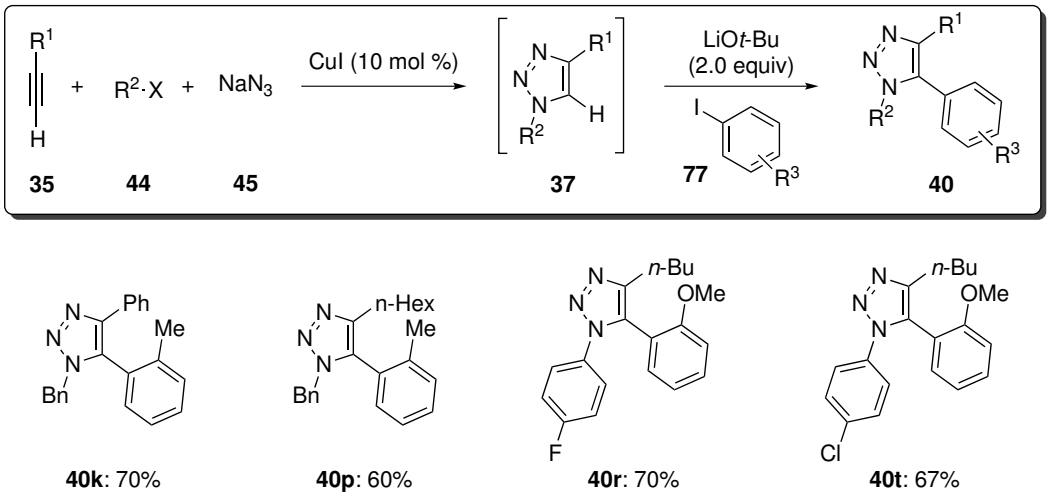
lations to proceed through reversible C–H bond activation and subsequent rate-limiting oxidative addition with aryl halides **25**. These results led to the development of widely applicable well-defined ruthenium(II) carboxylate catalyst **66** (Scheme 4.4).



Scheme 4.4: Ruthenium(II)-catalyzed direct arylations using well-defined complex **66**.

This method can find important applications in the pharmaceutical industry due to the mild reaction conditions and remarkable functional group compatability. As an extension of this method, further studies involving the development of non-directed ruthenium-catalyzed arylations would be challenging.

A benign one-pot methodology for the sequential synthesis of fully substituted 1,2,3-triazoles was established enabling the chemo-selective coupling of up to four components through the formation of one C–C- and three C–N bonds (Scheme 4.5).



Scheme 4.5: Copper-catalyzed sequential synthesis of fully substituted 1,2,3-triazoles.

However, the use of milder bases in this transformation would be of great interest.

5 Experimental

5.1 General remarks

All reactions and handling of reagents were performed under an atmosphere of dry nitrogen using Schlenk techniques. All glassware was oven-dried at 150 ℃ for at least 24 h, assembled hot and cooled under high vacuum prior to use. CH_2Cl_2 and DMF were dried and distilled from CaH_2 prior to their use. THF, Et_2O, toluene and 1,4-dioxane were dried over Na/benzophenone and freshly distilled prior to their use.

Separation and identification of the compounds

Chromatography: Analytical TLC was performed on 0.25 mm silica gel 60F plates (Macherey-Nagel) with 254 nm fluorescent indicator from Merck. Plates were visualized under ultraviolet light and developed by treatment with the $KMnO_4$ solution. Chromatographic purification of products was accomplished by flash column chromatography on Merck silica gel, grade 60 (0.063–0.200 mm, 70–230 mesh ASTM). **NMR**: Nuclear magnetic resonance (^{1}H and ^{13}C NMR) spectra were recorded at 250, 300, or 600 (^{1}H), 62.9, 75.5, or 125 [^{13}C, APT (Attached Proton Test)] MHz on Brucker AM 250, Varian Unity-300 and Inova 500 instruments in $CDCl_3$ solutions if not otherwise specified. Proton chemical shifts are reported in ppm relative to the residual peak of the deuterated solvent or tetramethylsilane: δ (ppm) = 0 for tetramethylsilane, 2.49 for [D_5]DMSO, 7.26 for $CHCl_3$. For the characterization of the observed signal multiplicities the following abbreviations were applied: s = singlet, d = doublet, t = triplet, q = quartet, quin = quintet, m = multiplet, as well as br = broad. ^{13}C chemical shifts are reported relative to the solvent peak or tetramethylsilane: 0 for tetramethylsilane, 39.5 for [D_5]DMSO, 77.0 for $CDCl_3$. **IR**: Bruker IFS 66 (FT-IR) and Bruker Alpha-P spectrometers, measured as KBr pellets or oils between KBr plates. **MS**: EI-MS: Finnigan MAT 95, 70 eV, DCI-MS: Finnigan MAT 95, 200 eV, reactant gas NH_3; ESI-MS: Finnigan LCQ. High resolution mass spectrometry (HRMS): APEX IV 7T FTICR, Bruker Daltonic. **Melting points**: Buchi 540 and Stuart SMP3 capillary melting point apparatus, uncorrected values.

5.2 Starting materials

The following starting materials were synthesized according to known literature procedures: phosphine chlorides **15b**,[99] **15c** and **15a**,[100] phosphine oxides **13a** and **13c**,[66] 4-bromo-3,5-dimethyl-1-phenyl-1*H*-pyrazole (**2r**),[101] lithium triisopropyl (pyridin-2-yl)borates **24a**–**24d**,[27] 1-(*m*-tolyl)-1*H*-pyrazole (**29i**), 1-(3-methoxyphenyl)-1*H*-pyrazole (**29j**), 1-(3-fluorophenyl)-1*H*-pyrazole (**29b**), 1-phenyl-1*H*-pyrazole (**29p**),[102] 1-(*o*-tolyl)-1*H*-pyrazole (**29h**), 1-(2-methoxyphenyl)-1*H*-pyrazole (**29f**).[103]

I thank my colleagues for their friendly donation of the following chemicals.
Dr. Robert Born: 4-*n*-Butyl-1-(2-fluorophenyl)-1*H*-1,2,3-triazole (**37g**); *Dr. Rubén Vicente*: 4-*n*-Butyl-1-(*m*-tolyl)-1*H*-1,2,3-triazole (**37e**), 4-*n*-butyl-1-(2-methoxyphenyl)-1*H*-1,2,3-triazole (**37f**), 2-{2-(trifluoromethyl)phenyl}pyridine (**29k**), 3-methyl-2-phenylpyridine (**29l**), 2-(2′-methoxyphenyl)pyridine (**29c**), (*E*)-2-styryl-4,5-dihydrooxazole (**29m**); *Dr. Petr Novák*: 1-(3-(Chlorophenyl))-1*H*-pyrazole (**29n**), 1-{3-(trifluoromethyl)phenyl}-1*H*-pyrazole (**29o**); *Dr. Anant Kapdi*: P-*tert*-butyl-P-(2′,6′-dimethoxy biphen-2-yl)phosphine chloride (**46**), P-*tert*-butyl-P-(2′,4′,6′-trimethoxy biphen-2-yl)phosphine oxide (**47**), P-*tert*-butyl-P-(*N*-2′,4′,6′-trimethoxyphenylpyrrol-2-yl)phosphine oxide (**48**); *Dipl. Chem. Sebastian Barfüßer*: TADDOL phoshine oxide **14a** and other derivatives **14b**–**14d**; *Dipl. Chem. Sabine Fenner*: 4-Acetylphenyl tosylate (**30a**), 3-acetylphenyl tosylate (**30b**), 4-methylcarbonylphenyl tosylate (**30c**), 2-naphthyl tosylate (**30d**), 4-methylphenyl tosylate (**30e**), 3,5-bis-(methylcarbonyl)phenyl tosylate (**30f**), 4-methoxycarbonylphenyl tosylate (**30g**); *Karsten Rauch*: 2-(*o*-Tolyl)pyridine (**29d**), 2-(*o*-tolyl)-4,5-dihydrooxazole (**29e**), 1,3-bis-[2,4,6-trimethylphenyl]-4,4,5-trimethyl-[1,3,2]-diazaphospholidine 2-oxide (**15b**), mesitylboronic acid (**41c**), 2,6-dimethylphenyl boronic acid (**41d**), 4-methoxy-2,6-dimethylphenyl boronic acid (**41e**), 1-adamantyl phosphine oxide (**56**).

All other chemicals were used as commercially available.

5.3 Representative procedures

Representative procedure A: Palladium-catalyzed Suzuki-Miyaura cross-coupling with aryl chlorides.
A suspension of $[Pd_2(dba)_3]$ (1.0 mol %) and (pre)ligand **46** (4.0 mol %) in dry 1,4-dioxane (2.0 mL) was stirred for 10 min at ambient temperature. Then, K_3PO_4 (1.50 mmol), aryl boronic acid (**41**) (0.75 mmol) and aryl chloride (**8**) (0.50 mmol) were added and the resulting mixture was heated at 110 °C for 20 h. H_2O (50 mL) and EtOAc (50 mL) were added to the cold reaction mixture. The separated aqueous phase was extracted with EtOAc (2 × 50 mL). The combined organic layers were dried over Na_2SO_4 and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (*n*-hexane/EtOAc), concentrated and dried under vacuum.

Representative procedure B: Palladium-catalyzed synthesis of tetra-*ortho*-substituted biaryls.
A suspension of $[Pd_2(dba)_3]$ (2.0–4.0 mol %) and (pre)ligand **15a** (8.0–16.0 mol %) in dry 1,4-dioxane (2.0 mL) was stirred for 10 min at ambient temperature. Then, CsF (1.50 mmol), arylboronic acid (**41**) (0.75 mmol) and aryl bromide (**2**) (0.50 mmol) were added and the resulting mixture was heated at 80–110 °C for 20 h. H_2O (50 mL) and EtOAc (50 mL) were added to the cold reaction mixture. The separated aqueous phase was extracted with EtOAc (2 × 50 mL). The combined organic layers were dried over Na_2SO_4 and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (*n*-hexane/EtOAc), concentrated and dried under vacuum.

Representative procedure C: Palladium-catalyzed Suzuki-Miyaura cross-coupling with 2-pyridyl boronates.
A suspension of $[Pd_2(dba)_3]$ (1.0–1.5 mol %), (pre)ligand **14d** (4.0–6.0 mol %), K_3PO_4 (1.50 mmol), 2-pyridyl boronate (**24**) (0.75 mmol), aryl halide (**2** or **8**) (0.50 mmol) in 1,4-dioxane (2.0 mL) was stirred under N_2 at 110 °C for 20 h. After the reaction mixture was cooled to ambient temperature, MTBE (50 mL) and H_2O (50 mL) were added. The separated aqueous phase was extracted with MTBE (3 × 50 mL). The combined organic layers were washed with brine (50 mL), dried over Na_2SO_4 and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (*n*-hexane/EtOAc), concentrated and dried under vacuum.

Representative procedure D: Palladium-catalyzed Kumada-Corriu cross-coupling of pyridin-2-yl nucleophiles

A suspension of $[Pd_2(dba)_3]$ (2.0 mol %) and (pre)ligand **56** (8.0 mol %) in THF (1.0 mL) was stirred for 10 min at ambient temperature. Aryl bromide (**2**) (1.00 mmol) was added and the suspension was stirred for further 5 min. Then, pyridin-2-yl magnesium bromide (**43**) (1.50 mmol, 0.3M in THF) was added dropwise over 3 min and the resulting suspension was stirred for 20 h at 60 °C. The starting Grignard reagent **43** was prepared according to the literature procedure[88] utilizing two equivalents of magnesium and a stoichiometric amount of dibromomethane. EtOAc (50 mL) and H_2O (50 mL) were added to the cold reaction mixture. The separated aqueous phase was extracted with EtOAc (2 × 50 mL). The combined organic layers were washed with H_2O (50 mL) and brine (50 mL), dried over Na_2SO_4 and concentrated *in vacuo*. The residue was purified by column chromatography on silica (*n*-hexane/EtOAc), concentrated and dried under vacuum.

Representative procedure E: Palladium-catalyzed Kumada-Corriu cross-coupling using complex **61**.

Pyridin-2-yl magnesium bromide (**43**) (1.50 mmol, 0.3M in THF) was added dropwise to a suspension of complex **61** (1.0 mol %) and aryl bromide (**2**) (1.00 mmol) in THF (1.0 mL) and the resulting suspension was stirred at 60 °C for 20 h . EtOAc (50 mL) and H_2O (50 mL) were added to the cold reaction mixture. The separated aqueous phase was extracted with EtOAc (2 × 50 mL). The combined organic layers were washed with H_2O (50 mL) and brine (50 mL), dried over Na_2SO_4 and concentrated *in vacuo*. The residue was purified by column chromatography on silica (*n*-hexane/EtOAc), concentrated and dried under vacuum.

Representative procedure F: Ruthenium-catalyzed direct arylations using complex **66**.

A suspension of **66** (5.0 mol %), pronucleophile (**29**) (0.50 mmol), electrophile (**8**) (0.75 mmol) and K_2CO_3 (1.00 mmol) in PhMe (2.0 mL) was stirred under N_2 at 120 °C for 18 h. MTBE (25 mL) was added to the cold reaction mixture and the resulting suspension was filtered through a short pad of Celite, which was further washed with MTBE (2 × 25 mL). The combined organic layers were concentrated in vacuum and the residue was purified by column chromatography on silica gel (*n*-hexane/EtOAc), concentrated and dried under vacuum.

Representative procedure G: Ruthenium-catalyzed formal dehydrative arylations using phenols.

A suspension of **66** (5.0 mol %), pronucleophile (**29**) (1.00 mmol), K_2CO_3 (2.00 mmol),

phenol (**1**) (1.20 mmol) and *p*-TsCl (1.20 mmol) in dry PhMe (2.0 mL) was stirred for 5 min at ambient temperature, and then for at 120 °C 18 h under N_2. At ambient temperature, EtOAc (70 mL) and H_2O (50 mL) were added to the reaction mixture and the separated aqueous phase was extracted with EtOAc (2 × 70 mL). The combined organic layers were washed with brine, dried over Na_2SO_4 and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (*n*-hexane/EtOAc) , concentrated and dried under vacuum.

Representative procedure H: Copper-catalyzed direct arylations of 1,2,3-triazoles **37**.
CuI (10.0 mol %), LiO*t*-Bu (2.00 mmol), 1,2,3-triazole (**37**) (1.00 mmol) and aryl iodide (**77**) (3.00 mmol) were treated with DMF (3.0 mL) and the resulting suspension was stirred under N_2 at 140 °C for 20 h. At ambient temperature, Et_2O (50 mL) and H_2O (50 mL) were added. The separated aqueous layer was extracted with Et_2O (2 × 75 mL). The combined organic layers were washed with *aq. sat.* NH_4Cl (50 mL), H_2O (50 mL) and brine (50 mL), dried over Na_2SO_4 and concentrated *in vacuum*. The residue was purified by column chromatography on silica gel (*n*-hexane/EtOAc), concentrated and dried under vacuum.

Representative procedure I: Copper-catalyzed sequential synthesis of fully substituted 1,2,3-triazoles **40**.
n-Alkyne (**35**) (1.00 mmol) was added to a suspension of azide **34** (1.00 mmol) and CuI (10.0 mol %) in DMF (3.0 mL). The mixture was stirred under N_2 at 60 °C for 4 h. At ambient temperature, LiO*t*-Bu (2.00 mmol), aryl iodide (**77**) (3.00 mmol) and DMF (2.0 mL) were added, and the resulting suspension was stirred under N_2 at 140 °C for 20 h. At ambient temperature, Et_2O (50 mL) and H_2O (50 mL) were added. The separated aqueous layer was extracted with Et_2O (2 × 75 mL). The combined organic layers were washed with *aq. sat.* NH_4Cl (50 mL), H2O (50 mL) and brine (50 mL), dried over Na_2SO_4 and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (*n*-hexane/EtOAc), concentrated and dried under vacuum.

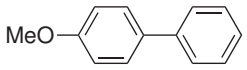
Representative procedure J: Copper-catalyzed four component synthesis.
A suspension of CuI (10.0 mol %) and NaN_3 (1.05 mmol) in DMF (3.0 mL) was treated with *n*-alkyne (**35**) (1.00 mmol), aryliodide (**77**) (1.00 mmol) and DMEDA (15.0 mol %) sequentially. The resulting mixture was stirred under N_2 for 2 h at ambient temperature. Then, LiO*t*-Bu (2.00 mmol), aryl iodide (**77**) (3.00 mmol) and DMF (2.0 mL) were added. The resulting suspension was stirred under N_2 at 140 °C for 20 h. At ambient temperature, Et_2O (50 mL) and H_2O (50 mL) were added. The separated aqueous layer

was extracted with Et_2O (2 × 75 mL). The combined organic layers were washed with sat. aq. NH_4Cl (50 mL), H_2O (50 mL) and brine (50 mL), dried over Na_2SO_4 and concentrated in vacuum. The residue was purified by column chromatography on silica gel (*n*-hexane/EtOAc), concentrated and dried under vacuum.

Representative procedure K: Copper-catalyzed sequential C–C/C–N bond formations.
CuI (20.0 mol %), LiO*t*-Bu (3.00 mmol), (benz)imidazole (**83**) (1.00 mmol) and aryl iodide (**77**) (5.00 mmol) were placed in a Schlenk tube and DMF (3.0 mL) was added. The resulting solution was stirred at 140 °C for 22 h under N_2. MTBE (75 mL) and H_2O (75 mL) were added to the cold reaction mixture. The separated aqueous phase was extracted with MTBE (2 × 75 mL). The combined organic layers were washed with H_2O (50 mL) and brine (50 mL), dried over Na_2SO_4 and concentrated *in vacuum*. The residue was purified by column chromatography on silica gel (*n*-hexane/EtOAc), concentrated and dried under vacuum.

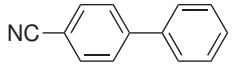
5.4 Analytical data

Synthesis of 4-methoxybiphenyl (9a)



The representative procedure A was followed using phenylboronic acid (**41a**) (91 mg, 0.75 mmol), 4-chloroanisole (**8b**) (76 mg, 0.50 mmol), $[Pd_2(dba)_3]$ (4.6 mg, 0.005 mmol), **46** (6.4 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-hexane/EtOAc: 150/1 → 50/1) yielded **9a** (91 mg, 93%) as a colorless solid. m.p. 84–86 °C, Lit.:[66] 86–88 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.61 (m, 2H), 7.58 (d, J = 8.8 Hz, 2H), 7.46 (t, J = 7.5 Hz, 2H), 7.35 (t, J = 7.3 Hz, 1H), 7.04 (d, J = 8.8 Hz, 2H), 3.88 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 159.1 (C_q), 140.8 (C_q), 133.7 (C_q), 128.7 (CH), 128.1 (CH), 126.7 (CH), 126.6 (CH), 114.2 (CH), 55.3 (CH_3).
IR (KBr): 2964, 1606, 1522, 1489, 1251, 1184, 1035, 834, 760 cm^{-1}.
MS (EI) m/z (relative intensity) 184 (100) [M^+], 169 (55), 141 (57), 115 (40), 43 (8).
HR-MS (ESI): m/z calcd for $C_{13}H_{12}O$ 184.0888, found 184.0886.
The spectral data were in accordance with those reported in the literature.[66]

Synthesis of 4-cyanobiphenyl (9b)



The representative procedure A was followed using phenylboronic acid (**41a**) (91 mg, 0.75 mmol), 4-chlorobenzonitrile (**8c**) (69 mg, 0.50 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **46** (6.4 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-pentane/Et_2O: 150/1 → 50/1) yielded **9b** (88 mg, 99%) as a colorless solid. m.p. 83–85 °C, Lit.:[104] 85–86 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.89–7.80 (m, 2H), 7.80–7.74 (m, 2H), 7.58 (m, 1H), 7.53–7.44 (m, 2H), 7.19–7.12 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 195.2 (C_q), 167.0, 163.6, 137.4, 133.7, 133.7, 132.6, 132.5, 132.4, 129.8, 128.3, 115.5, 115.2.

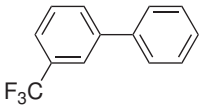
IR (KBr): 3523, 2470, 1605, 1483, 1397, 1262, 1178, 1007, 848, 770, 697 cm^{-1}.

MS (EI) m/z (relative intensity) 179 (100) [M^+], 151 (20), 76 (10).

HR-MS (EI): m/z calcd for $C_{13}H_9N$ 179.0735, found 179.0736.

The spectral data were in accordance with those reported in the literature.[105]

Synthesis of 3-(trifluoromethyl)biphenyl (9c)



The representative procedure A was followed using phenylboronic acid (**41a**) (91 mg, 0.75 mmol), 3-chlorobenzotrifluoride (**8d**) (90 mg, 0.50 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **46** (6.4 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-pentane/Et_2O: 50/1) yielded **9c** (114 mg, 94%) as a colorless oil.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.85 (d, J = 0.7 Hz, 1H), 7.78 (d, J = 7.4 Hz, 1H), 7.71–7.55 (m, 4H), 7.55–7.32 (m, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 141.9 (C_q), 140.5 (C_q), 139.7 (C_q), 131.1 (C_q, $^2J_{C–F}$ = 32 Hz), 130.4 (CH), 130.3 (CH), 129.4 (CH), 129.1 (CH), 128.9 (CH), 127.9 (CH), 127.1 (CH), 124.1 (C_q, $^1J_{C–F}$ = 272 Hz), 124.6 (CH, $^3J_{C–F}$ = 4 Hz), 123.8 (CH, $^3J_{C–F}$ = 4 Hz).

^{19}F-NMR (282 MHz, $CDCl_3$): δ = -62.6 (s).

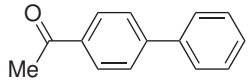
IR (KBr): 3064, 1593, 1483, 1455, 1424, 1259, 1162, 1119, 1045, 897 cm^{-1}.

MS (EI) m/z (relative intensity) 222 (100) [M^+], 201 (20), 152 (28), 58 (14), 43 (64).

HR-MS (ESI): m/z calcd for $C_{13}H_9F_3$ 222.0656, found 222.0650.

The spectral data were in accordance with those reported in the literature.[106]

Synthesis of 4-acetylbiphenyl (9d)



The representative procedure A was followed using phenylboronic acid (**41a**) (91 mg, 0.75 mmol), 4-chloroacetophenone (**8e**) (74 mg, 0.48 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **46** (6.4 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-pentane/Et_2O: 150/1 → 50/1) yielded **9d** (90 mg, 96%) as a colorless solid. m.p. 116–118 °C, Lit.:[107] 117–118 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.02 (d, J = 8.6 Hz, 2H), 7.67 (d, J = 8.6 Hz, 2H), 7.64–7.59 (m, 2H), 7.49–7.35 (m, 3H), 2.62 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 197.7 (C_q), 145.7 (C_q), 139.8 (C_q), 135.8 (C_q), 128.9 (CH), 128.9 (CH), 128.2 (CH), 127.2 (CH), 127.2 (CH), 26.6 (CH_3).

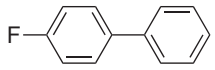
IR (KBr): 3522, 2359, 1681, 1602, 1404, 1358, 1263, 1076, 960, 765 cm^{-1}.

MS (EI) m/z (relative intensity) 196 (42) [M^+], 181 (100), 152 (56), 76 (12), 43 (20).

HR-MS (ESI): m/z calcd for $C_{14}H_{12}O$ 196.0888, found 196.0889

The spectral data were in accordance with those reported in the literature.[66]

Synthesis of 4-fluorobiphenyl (9e)



The representative procedure A was followed using phenylboronic acid (**41a**) (91 mg, 0.75 mmol), 1-chloro-4-fluorobenzene (**8f**) (74 mg, 0.57 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **46** (6.4 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-pentane) yielded **9e** (92 mg, 94%) as a colorless solid. m.p. 67–69 °C. Lit.:[108] 68–69 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.59–7.52 (m, 4H), 7.48–7.41 (m, 2H), 7.36 (m, 1H), 7.18–7.09 (m, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 162.3 (C_q, $^1J_{C–F}$ = 246 Hz), 140.1 (C_q, $^4J_{C–F}$ = 3 Hz), 137.2 (C_q), 128.7 (CH), 128.5 (CH, $^3J_{C–F}$ = 8 Hz), 127.0 (CH), 126.9 (CH), 115.5 (CH, $^2J_{C–F}$ = 21 Hz).

^{19}F-NMR (282 MHz, $CDCl_3$): δ = -115.9 (m).

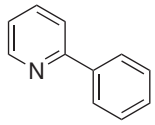
IR (KBr): 3757, 2634, 1597, 1520, 1487, 1397, 1239, 1105, 837, 759 cm^{-1}.

MS (EI) m/z (relative intensity) 172 (88) [M^+], 149 (63), 97 (46), 69 (68), 43 (100).

HR-MS (ESI): m/z calcd for $C_{12}H_9F$ 172.0688, found 172.0691.

The spectral data were in accordance with those reported in the literature.[109]

Synthesis of 2-phenylpyridine (9f)



The representative procedure A was followed using phenylboronic acid (**41a**) (91 mg, 0.75 mmol), 2-chloropyridine (**8g**) (60 mg, 0.53 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **46** (6.4 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-pentane/Et_2O: 10/1 → 2/1 → 1/1) yielded **9f** (81 mg, 99%) as a yellow oil.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.71 (dt, J = 4.8, 1.4 Hz, 1H), 8.0X–7.98 (m, 2H), 7.77–7.71 (m, 2H), 7.52–7.38 (m, 3H), 7.28–7.19 (m, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$) δ = 157.3 (C_q), 149.5 (CH), 139.3 (C_q), 136.6 (CH), 128.8 (CH), 128.6 (CH), 126.8 (CH), 122.0 (CH), 120.4 (CH).

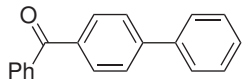
IR (ATR): 3061, 1580, 1564, 1467, 1448, 1423, 1073, 739 cm^{-1}.

MS (EI) m/z (relative intensity) 155 (100) [M^+], 127 (13), 102 (6), 77 (11), 43 (18).

HR-MS (ESI): m/z calcd for $C_{11}H_9N$ 155.0735, found 155.0728.

The spectral data were in accordance with those reported in the literature.[110]

Synthesis of 4-phenylbenzophenone (9g)



The representative procedure A was followed using phenylboronic acid (**41a**) (91 mg, 0.75 mmol), 4-chlorobenzophenone (**8h**) (109 mg, 0.50 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **46** (6.4 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-pentane/Et_2O: 150/1 → 50/1) yielded **9g** (125 mg, 97%) as a colorless soild. m.p. 104–106 °C. Lit.:[111] 105–106 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.93–7.82 (m, 4H), 7.73–7.56 (m, 5H), 7.52–7.45 (m, 4H), 7.40 (m, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 196.2 (C_q), 145.1 (C_q), 139.9 (C_q), 137.7 (C_q), 136.1 (C_q), 132.3 (CH), 130.6 (CH), 129.9 (CH), 128.9 (CH), 128.2 (CH), 128.1 (CH), 127.2 (CH), 126.9 (CH).

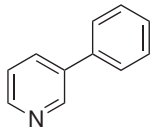
IR (KBr): 3522, 1644, 1602, 1445, 1318, 1290, 940, 851, 694 cm^{-1}.

MS (EI) m/z (relative intensity) 258 (90) [M^+], 181 (100), 152 (53), 105 (33), 77 (35), 51 (10).

HR-MS (EI): m/z calcd for $C_{19}H_{14}O$ 258.1045, found 258.1045.

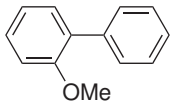
The spectral data were in accordance with those reported in the literature.[85]

Synthesis of 3-phenylpyridine (9h)



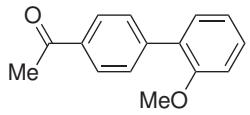
The representative procedure A was followed using phenylboronic acid (**41a**) (91 mg, 0.75 mmol), 3-chloropyridine (**8i**) (75 mg, 0.66 mmol), $[Pd_2(dba)_3]$ (4.6 mg, 0.005 mmol), **46** (6.4 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-pentane/Et_2O: 5/1) yielded **9h** (89 mg, 87%) as a yellow oil.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.85 (d, J = 1.8 Hz, 1H), 8.59 (dd, J = 4.8, 1.5 Hz, 1H), 7.86 (ddd, J = 7.9, 2.4, 1.6 Hz, 1H), 7.60–7.55 (m, 2H), 7.51–7.31 (m, 4H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 148.3 (CH), 148.2 (CH), 137.7 (C_q), 136.4 (C_q), 134.1 (CH), 128.9 (CH), 127.9 (CH), 127.0 (CH), 123.4 (CH).
IR (ATR): 2996, 2836, 1602, 1513, 1459, 1431, 1242, 1020, 776 cm^{-1}.
MS (EI) m/z (relative intensity) 155 (100) $[M^+]$, 127 (18), 102 (17), 76 (8), 51 (12).
HR-MS (ESI): m/z calcd for $C_{11}H_9N$ 155.0735, found 155.0731.
The spectral data were in accordance with those reported in the literature.[66]

Synthesis of 2-methoxybiphenyl (9i)



The representative procedure A was followed using phenylboronic acid (**41a**) (91 mg, 0.75 mmol), 2-chloroanisole (**8j**) (78 mg, 0.55 mmol), $[Pd_2(dba)_3]$ (4.6 mg, 0.005 mmol), **46** (6.4 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-pentane/Et_2O: 100/1) yielded **9i** (90 mg, 89%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.57–7.52 (m, 2H), 7.46–7.39 (m, 2H), 7.38–7.30 (m, 3H), 7.08–6.97 (m, 2H), 3.83 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 156.3 (C_q), 138.4 (C_q), 130.8 (CH), 130.6 (C_q), 129.4 (CH), 128.5 (CH), 127.9 (CH), 126.8 (CH), 120.8 (CH), 111.2 (CH), 55.6 (CH_3).
IR (ATR): 2962, 2834, 1737, 1482, 1429, 1258, 1009, 791 cm^{-1}.
MS (EI) m/z (relative intensity) 184 (100) $[M^+]$, 169 (54), 141 (36), 115 (50), 58 (15), 43 (72).
HR-MS (ESI): m/z calcd for $C_{13}H_{12}O$ 184.0888, found 184.0883.
The spectral data were in accordance with those reported in the literature.[112]

Synthesis of 4-acetyl-2′-methoxybiphenyl (9j)



The representative procedure A was followed using 2-anisyl boronic acid (**41b**) (114 mg, 0.75 mmol), 4-chloroacetophenone (**8e**) (79 mg, 0.51 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **46** (6.4 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-pentane/Et_2O: 10/1 → 5/1 → 2/1) yielded **9j** (103 mg, 89%) as a colorless oil.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.01 (d, J = 8.6 Hz, 2H), 7.64 (d, J = 8.6 Hz, 2H), 7.41–7.32 (m, 2H), 7.06 (td, J = 7.5, 1.1 Hz, 1H), 7.01 (d, J = 8.2 Hz, 1H), 3.83 (s, 3H), 2.63 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 197.6 (C_q), 156.3 (C_q), 143.5 (C_q), 135.4 (C_q), 130.6 (CH), 129.6 (CH), 129.5 (CH), 129.4 (C_q), 128.0 (CH), 120.9 (CH), 111.3 (CH), 55.6 (CH_3), 26.7 (CH_3).

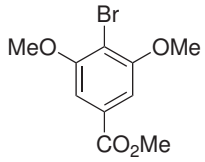
IR (ATR): 3058, 2943, 1675, 1597, 1448, 1376, 1195, 978, 735 cm^{-1}.

MS (EI) m/z (relative intensity) 226(16) [M^+], 211(28), 168 (12), 133 (14), 120 (15), 105 (100), 77 (48), 51 (18), 43 (27).

HR-MS (ESI): m/z calcd for $C_{15}H_{14}O_2$ 226.0994, found 226.0996.

The spectral data were in accordance with those reported in the literature.[113]

Synthesis of 4-bromo-3,5-dimethoxybenzoic acid methylester (2s)



4-Bromo-3,5-dimethylbenzoic acid (1.31 g, 5.00 mmol), K_2CO_3 (0.73 g, 5.50 mmol), dimethylsulfate (0.57 mL, 6.00 mmol) were stirred at 80 °C in acetone (25 mL) for 4 h. The reaction mixture was cooled and concentrated *in vacuo*. The crude product was dissolved in H_2O (50 mL) and MTBE (50 mL). The aqueous phase was extracted with MTBE (4 × 50 mL), and the combined organic phase was dried over Na_2SO_4, filtered and concentrated to give **2s** (1.27 g, 92%) as a colorless solid. m.p. 120–122 °C. Lit.:[114] 119–120 °C.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.19 (s, 2H), 3.91 (s, 6H), 3.89 (s, 3H).

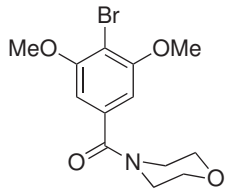
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 166.2 (C_q), 156.8 (C_q), 130.0 (C_q), 106.5 (C_q), 105.4 (CH), 56.6 (CH_3), 52.4 (CH_3).

IR (KBr): 3569, 2542, 1717, 1589, 1408, 1333, 1243, 1120, 1003, 855, 760 cm^{-1}.

MS (ESI) m/z (relative intensity) 276 (100) [M+H^+], 243 (54), 215 (14), 157 (10), 105

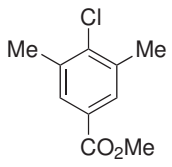
(7), 63 (13).
HR-MS (ESI): m/z calcd for $C_{10}H_{11}O_4Br+Na^+$ 296.9733, found 296.9737.
The analytical data were in accordance with those reported in the literature.[115]

Synthesis of (4-bromo-3,5-dimethoxyphenyl)(morpholino)methanone (2t)



To a solution of 4-bromo-3,5-dimethoxybenzoic acid (1.31 g, 5.00 mmol) in CH_2Cl_2 (10 mL) were added T3P® (4.76 g, 8.50 mmol, 56.7% in EtOAc), morpholine (0.58 mL, 6.50 mmol) and Et_3N (2.00 mL, 15.0 mmol) and the resulting clear solution was stirred at ambient temperature overnight. The reaction mixture was diluted with CH_2Cl_2 (50 mL), then H_2O (50 mL) and HCl (50 mL, 2 N) were added sequentially. The aqueous phase was extracted with CH_2Cl_2 (2 × 30 mL), and the combined organic phase was dried over Na_2SO_4, filtered and concentrated. The resulting crude product was purified by column chromatography (*n*-pentane/MTBE: 1/1) to yield **2t** (1.65 g, quant.) as a colorless solid.
m.p. 82–84 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 6.55 (s, 2H), 3.87 (s, 6H), 3.63 (s_{br}, 8H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 169.4 (C_q), 157.1 (C_q), 135.4 (C_q), 103.2 (CH), 102.6 (C_q), 66.8 (CH_2), 56.6 (CH_2).
IR (KBr): 3438, 2970, 2862, 1632, 1579, 1460, 1404, 1327, 1235, 1030, 855, 758 cm^{-1}.
MS (ESI) m/z (relative intensity) 329 (45) [M^+], 245 (100), 215 (18), 202 (15), 187 (14), 165 (20), 86 (28), 56 (36), 43 (76).
HR-MS (ESI): m/z calcd for $C_{13}H_{16}NO_4Br+H^+$ 330.0335, found 330.0337.

Synthesis of 4-chloro-3,5-dimethylbenzoic acid methylester (8q)



4-Chloro-3,5-dimethylbenzoic acid (1.85 g, 10.0 mmol), K_2CO_3 (1.52 g, 11.0 mmol) and dimethylsulfate (1.10 mL, 12.0 mmol) were stirred at 80 °C in acetone (25 mL) for 4 h. The reaction mixture was cooled and concentrated *in vacuo*. The crude material was poured into H_2O and MTBE mixture (100 mL each). The aqueous phase was extracted with MTBE (2 × 50 mL), and combined organic phase was dried over Na_2SO_4,

filtered and concentrated. The crude product was purified by column chromatography (*n*-pentane/MTBE: 20/1 → 10/1) to give **8q** (1.49 g, 75%) as a colorless solid. m.p. 52–54 °C.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.75 (s, 2H), 3.90 (s, 3H), 2.41 (s, 6H).

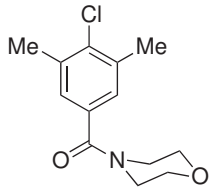
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 166.7 (C_q), 139.7 (C_q), 136.5 (C_q), 129.3 (CH), 127.6 (C_q), 52.1 (CH_3), 20.7 (CH_3).

IR (KBr): 3054, 2954, 1713, 1592, 1435, 1313, 1221, 1126, 1043, 768 cm^{-1}.

MS (EI) m/z (relative intensity) 198 (38) [M^+], 167 (100), 139 (16), 103 (20), 77 (20).

HR-MS (EI): m/z calcd for $C_{10}H_{11}O_2Cl$+Na 221.0340, found 221.0342.

Synthesis of (4-chloro-3,5-dimethylphenyl)(morpholino)methanone (8r)



To a solution of 4-chloro-3,5-dimethoxybenzoic acid (1.85 g, 10.0 mmol) in CH_2Cl_2 (20 mL) were added T3P® (9.50 mL, 17.0 mmol, 56.7% in EtOAc), morpholine (1.10 mL, 13.0 mmol) and Et_3N (4.20 mL, 30.0 mmol) and the resulting clear solution was stirred at ambient temperature overnight. The reaction mixture was poured into a mixture of CH_2Cl_2 (70 mL) and H_2O (100 mL), then HCl (50 mL, 2N) was added subsequently. The aqueous phase was extracted with CH_2Cl_2 (2 × 50 mL), and the combined organic phase was dried over Na_2SO_4, filtered and concentrated. The resulting crude product was purified by column chromatography (*n*-pentane/MTBE: 1/1) to yield **8r** (2.857 g, 93%) as a light-brown solid. m.p. 110–112 °C.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.11 (s, 2H), 3.68 (s, 6H), 2.38 (s_{br}, 8H).

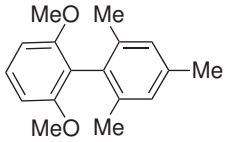
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 169.7 (C_q), 136.7 (C_q), 136.2 (C_q), 133.0 (C_q), 126.9 (CH), 66.8 (CH_3), 20.7 (CH_3).

IR (KBr): 3499, 2955, 2857, 1767, 1626, 1419, 1312, 1236, 1108, 1046, 953, 754 cm^{-1}.

MS (ESI) m/z (relative intensity) 253 (20) [M^+], 167 (100), 139 (10), 103 (16), 77 (12).

HR-MS (ESI): m/z calcd for $C_{13}H_{16}NO_2Cl$+Na^+ 276.0762, found 276.0762.

Synthesis of 2′,6′-dimethoxy-2,4,6-trimethylbiphenyl (9k)



The representative procedure B was followed, using mesitylboronic acid (**41c**) (123 mg, 0.75 mmol), 2,6-dimethoxybromobenzene (**2b**) (109 mg, 0.50 mmol), [$Pd_2(dba)_3$] (9.2 mg, 0.01 mmol), **15a** (17.8 mg, 0.04 mmol) and CsF (228 mg, 1.50 mmol) at 80 °C. After 20 h, purification by chromatography (*n*-hexane/EtOAc: 10/1) yielded **9k** (127 mg, 99%) as an off-white solid. m.p. 124–126 °C. Lit.:[116] 127–128 °C

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.28 (t, J = 8.3 Hz, 1H), 6.91 (s, 2H), 6.63 (d, J = 8.3 Hz, 2H), 3.69 (s, 6H), 2.30 (s, 3H), 1.94 (s, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$) δ = 157.1 (C_q), 136.5 (C_q), 135.9 (C_q), 130.6 (C_q), 128.1 (CH), 127.4 (CH), 117.2 (C_q), 103.5 (CH), 55.5 (CH_3), 21.0 (CH_3), 19.8 (CH_3).

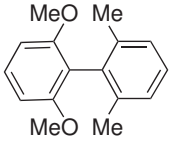
IR (KBr): 2957, 2835, 1590, 1469, 1265, 1112, 1002, 853, 737 cm^{-1}.

MS (EI) m/z (relative intensity) 256 (100) [M^+], 241 (34), 226 (15), 210 (17), 105 (6).

HR-MS (ESI): m/z calcd for $C_{17}H_{20}O_2$+Na^+ 279.1356, found 279.1360.

The analytical data were in accordance with those reported in the literature.[117]

Synthesis of 2,6-dimethoxy-2′,6′-dimethylbiphenyl (9l)



The representative procedure B was followed, using 2,6-dimethyl phenylboronic acid (**41d**) (112 mg, 0.75 mmol), 2,6-dimethoxy bromobenzene (**2b**) (109 mg, 0.50 mmol), [$Pd_2(dba)_3$] (9.2 mg, 0.01 mmol), **15a** (17.8 mg, 0.04 mmol) and CsF (228 mg, 1.50 mmol) at 80 °C. After 20 h, purification by chromatography (*n*-hexane/EtOAc: 10/1) yielded **9l** (111 mg, 92%) as an off-white solid. m.p. 107–109 °C. Lit.:[118] 107–109 °C.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.32 (t, J = 8.3 Hz, 1H), 7.20–7.08 (m, 3H), 6.66 (d, J = 8.4 Hz, 2H), 3.71 (s, 6H), 2.00 (s, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$) δ = 157.4 (C_q), 137.1 (C_q), 134.0 (C_q), 128.6 (CH), 127.0 (CH), 126.8 (CH), 117.6 (C_q), 103.9 (CH), 55.8 (CH_3), 20.1 (CH_3).

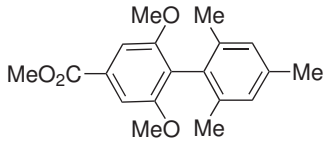
IR (KBr): 3055, 2960, 2837, 2389, 2348, 1590, 1469, 1433, 1248, 1110, 1036, 737 cm^{-1}.

MS (EI) m/z (relative intensity) 242 (100) [M^+], 227 (12), 195 (20), 165 (10), 105 (6).

HR-MS (ESI): m/z calcd for $C_{16}H_{19}O_2$ 243.1380, found 243.1380.

The analytical data were in accordance with those reported in the literature.[17]

Synthesis of 2,6-dimethoxy-2′,4′,6′-trimethylbiphenyl-4-carboxylic acid methylester (9m)



The representative procedure B was followed, using mesitylboronic acid (**41c**) (123 mg, 0.75 mmol), 4-bromo-3,5-dimethoxy benzoic acid methylester (**2s**) (138 mg, 0.50 mmol), [$Pd_2(dba)_3$] (9.2 mg, 0.01 mmol), **15a** (17.8 mg, 0.04 mmol) and CsF (228 mg, 1.50 mmol) at 80 °C. After 20 h, purification by chromatography (*n*-hexane/EtOAc: 10/1) yielded **9m** (150 mg, 95%) as an off-white solid. m.p. 130–131 °C.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.34 (s, 2H), 6.93 (s, 2H), 3.95 (s, 3H), 3.76 (s, 6H), 2.31 (s, 3H), 1.93 (s, 6H).

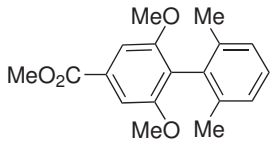
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 167.1 (C_q), 157.4 (C_q), 136.8 (C_q), 136.4 (C_q), 130.4 (C_q), 130.1 (C_q), 127.9 (CH), 122.6 (C_q), 105.1 (CH), 55.9 (CH_3), 52.2 (CH_3), 21.2 (CH_3), 19.8 (CH_3).

IR (KBr): 2956, 2836, 1719, 1579, 1464, 1410, 1325, 1225, 1127, 999, 860, 746 cm^{-1}.

MS (EI) m/z (relative intensity) 314 (100) [M^+], 283 (4), 165 (3), 55 (5), 43 (15).

HR-MS (ESI): m/z calcd for $C_{19}H_{23}O_4$ 315.1591, found 315.1590.

Synthesis of 2,6-dimethoxy-2′,6′-dimethylbiphenyl-4-carboxylic acid methylester (9n)



The representative procedure B was followed, using 2,6-dimethyl phenylboronic acid (**41d**) (112 mg, 0.75 mmol), 4-bromo-3,5-dimethoxy benzoic acid methylester (**2s**) (138 mg, 0.50 mmol), [$Pd_2(dba)_3$] (9.2 mg, 0.01 mmol), **15a** (17.8 mg, 0.04 mmol) and CsF (228 mg, 1.50 mmol) at 80 °C. After 20 h, purification by chromatography (*n*-hexane/EtOAc: 10/1) yielded **9n** (125 mg, 76%) as an off-white solid. m.p. 124–126 °C.

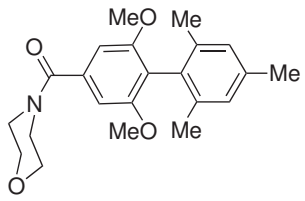
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.37 (s, 2H), 7.20 (m, 1H), 7.12 (d, J = 7.9 Hz, 2H), 3.97 (s, 3H), 3.78 (s, 6H), 1.98 (s, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$) δ = 167.0 (C_q), 157.2 (C_q), 136.6 (C_q), 133.2 (C_q), 130.6 (C_q), 127.4 (CH), 126.9 (CH), 122.7 (C_q), 105.2 (CH), 55.9 (CH_3), 52.2 (CH_3), 19.9 (CH_3).

IR (KBr): 3413, 3019, 2360, 1713, 1575, 1458, 1405, 1320, 1125, 996, 860, 748 cm^{-1}.

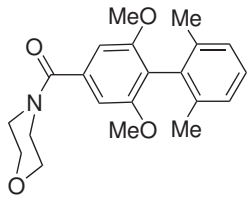
MS (EI) m/z (relative intensity) 300 (100) [M^+], 269 (8), 225 (2), 128 (4), 59 (5).
HR-MS (ESI): m/z calcd for $C_{18}H_{21}O_4$ 301.1434, found 301.1436.

Synthesis of (2,6-dimethoxy-2′,4′,6′-trimethylbiphenyl-4-yl)(morpholino)methanone (9o)



The representative procedure B was followed, using mesitylboronic acid (**41c**) (123 mg, 0.75 mmol), (4-bromo-3,5-dimethoxyphenyl) (morpholino) methanone (**2t**) (165 mg, 0.50 mmol), [$Pd_2(dba)_3$] (9.2 mg, 0.01 mmol), **15a** (17.8 mg, 0.04 mmol) and CsF (228 mg, 1.50 mmol) at 80 °C. After 20 h, purification by chromatography (*n*-hexane/EtOAc: 10/1) yielded **9o** (135 mg, 73%) as an off-white solid. m.p. 147–149 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 6.94 (s, 2H), 6.67 (s, 2H), 3.76 (s_{br}, 8H), 3.72 (s, 6H), 2.32 (s, 3H), 1.95 (s, 6H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 170.6 (C_q), 157.6 (C_q), 136.7 (C_q), 136.7 (C_q), 135.6 (C_q), 130.0 (C_q), 127.9 (CH), 119.3 (C_q), 102.7 (CH), 67.0 (2 x CH_2), 55.9 (CH_3), 21.3 (CH_3), 20.0 (CH_3).
IR (KBr): 2967, 2858, 1635, 1571, 1460, 1408, 1317, 1267, 1125, 855, 737 cm^{-1}.
MS (EI) m/z (relative intensity) 369 (78) [M^+], 283 (100), 256 (34), 225 (8), 165 (6), 86 (5), 56 (26), 42 (6).
HR-MS (ESI): m/z calcd for $C_{22}H_{27}NO_4$+Na^+ 392.1832, found 392.1844.

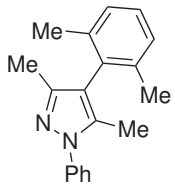
Synthesis of (2,6-dimethoxy-2′,6′-dimethylbiphenyl-4-yl)(morpholino)methanone (9p)



The representative procedure B was followed, using 2,6-dimethyl phenylboronic acid (**41d**) (112 mg, 0.75 mmol), 4-bromo-3,5-dimethoxyphenyl (morpholino)methanone (**2t**) (165 mg, 0.50 mmol), [$Pd_2(dba)_3$] (9.2 mg, 0.01 mmol), **15a** (17.8 mg, 0.04 mmol) and CsF (228 mg, 1.50 mmol) at 80 °C. After 20 h, purification by chromatography (*n*-hexane/EtOAc: 1/1) yielded **9p** (127 mg, 71%) as a colorless solid. m.p. 174–176 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.17 (m, 1H), 7.10 (d, J = 6.7 Hz, 2H), 6.68 (s, 2H),

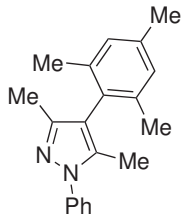
3.76 (s_{br}, 8H), 3.76 (s, 6H), 1.98 (s, 6H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 170.5 (C_q), 157.4 (C_q), 136.8 (C_q), 135.7 (C_q), 133.1 (C_q), 127.3 (CH), 126.8 (CH), 119.2 (C_q), 102.7 (CH), 66.9 (CH_2), 66.9 (CH_2), 55.9 (CH_3), 20.0 (CH_3).
IR (KBr): 2965, 2920, 2859, 1635, 1571, 1459, 1407, 1317, 1236, 1124, 963, 738 cm^{-1}.
MS (EI) m/z (relative intensity) 355 (100) [M^+], 340 (9), 269 (93), 242 (55), 226 (13), 211 (16), 165 (16), 127 (6), 55 (8).
HR-MS (ESI): m/z calcd for $C_{21}H_{26}NO_4$ 356.1856, found 356.1851.

Synthesis of 4-(2,6-dimethylphenyl)-3,5-dimethyl-1-phenyl-1*H*-pyrazole (9q)



The representative procedure B was followed using 2,6-dimethyl phenylboronic acid (**41d**) (112 mg, 0.75 mmol), 4-bromo-3,5-dimethyl-1-phenyl-1*H*-pyrazole (**2r**) (141 mg, 0.56 mmol), [$Pd_2(dba)_3$] (18.3 mg, 0.02 mmol), **15a** (35.6 mg, 0.08 mmol) and CsF (228 mg, 1.50 mmol) at 80 °C. After 20 h, purification by chromatography (*n*-hexane/EtOAc: 10/1) yielded **9q** (139 mg, 90%) as a yellow oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.56–7.44 (m, 4H), 7.38–7.31 (m, 1H), 7.22–7.11 (m, 3H), 2.09 (s, 6H), 2.07 (s, 6H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 147.4 (C_q), 140.2 (C_q), 138.2 (C_q), 136.1 (C_q), 132.3 (C_q), 129.0 (CH), 127.4 (CH), 127.1 (CH), 127.0 (CH), 124.4 (CH), 119.2 (C_q), 20.5 (CH_3), 12.2 (CH_3), 11.3 (CH_3).
IR (KBr): 3062, 2922, 2864, 1597, 1504, 1379, 1320, 1140, 1024, 766, 697 cm^{-1}.
MS (EI) m/z (relative intensity) 276 (100) [M^+], 261 (44), 246 (8), 172 (56), 130 (14), 91 (14), 77 (48), 51 (20).
HR-MS (ESI): m/z calcd for $C_{19}H_{21}N_2$ 277.1699, found 277.1703.

Synthesis of 3,5-dimethyl-4-mesityl-1-phenyl-1*H*-pyrazole (9r)



The representative procedure B was followed using mesitylboronic acid (**41c**) (123 mg, 0.75 mmol), 4-bromo-3,5-dimethyl-1-phenyl-1*H*-pyrazole (**2r**) (148 mg, 0.59 mmol), [$Pd_2(dba)_3$] (18.3 mg, 0.02 mmol), **15a** (35.6 mg, 0.08 mmol) and CsF (228 mg, 1.50 mmol) at 80 °C. After 20 h, purification by chromatography (*n*-hexane/EtOAc: 10/1) yielded **9r** (162 mg, 95%) as a colorless oil.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.56–7.43 (m, 4H), 7.34 (tt, J = 6.5, 1.4 Hz, 1H), 6.97 (s, 2H), 2.34 (s, 3H), 2.07 (s, 6H), 2.06 (s, 6H).

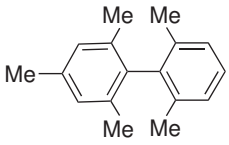
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 147.6 (C_q), 140.2 (C_q), 138.0 (C_q), 136.8 (C_q), 136.2 (C_q), 129.2 (C_q), 128.9 (CH), 128.0 (CH), 126.9 (CH), 124.4 (CH), 119.1 (C_q), 21.1 (CH_3), 20.4 (CH_3), 15.4 (CH_3), 12.3 (CH_3), 11.4 (CH_3).

IR (KBr): 2919, 2857, 1599, 1505, 1378, 1363, 1139, 1023, 851, 762, 697 cm^{-1}.

MS (EI) m/z (relative intensity) 290 (100) [M^+], 277 (46), 260 (24), 218 (8), 182 (12), 115 (18), 77 (53), 51 (18).

HR-MS (ESI): m/z calcd for $C_{20}H_{23}N_2$ 291.1856, found 291.1860.

Synthesis of 2,2′,4,6,6′-pentamethylbiphenyl (9s)



The representative procedure B was followed using mesitylboronic acid (**41c**) (123 mg, 0.75 mmol), 2,6-dimethyl bromobenzene (**2u**) (93 mg, 0.50 mmol), [$Pd_2(dba)_3$] (18.3 mg, 0.02 mmol), **15a** (35.6 mg, 0.08 mmol) and CsF (228 mg, 1.50 mmol) at 80 °C. After 20 h, purification by chromatography (*n*-hexane/EtOAc: 100/1) yielded **9s** (97 mg, 86%) as a colorless oil.

The representative procedure B was followed, using 2,6-dimethyl phenylboronic acid (**41d**) (112 mg, 0.75 mmol), bromomesitylene (**2j**) (100 mg, 0.50 mmol), [$Pd_2(dba)_3$] (18.3 mg, 0.02 mmol), **15a** (35.6 mg, 0.08 mmol) and CsF (228 mg, 1.50 mmol) at 80 °C. After 20 h, purification by chromatography (*n*-hexane/EtOAc: 100/1) yielded **9as** (89 mg, 79%) as a colorless oil.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.20–7.09 (m, 3H), 6.96 (s, 2H), 2.35 (s, 3H), 1.91 (s, 6H), 1.87 (s, 6H).

^{13}C-NMR (75 MHz, $CDCl_3$) δ = 140.0 (C_q), 136.9 (C_q), 136.1 (C_q), 135.7 (C_q), 135.2 (C_q), 128.2 (CH), 127.3 (CH), 126.7 (CH), 21.1 (CH_3), 19.9 (CH_3), 19.7 (CH_3).

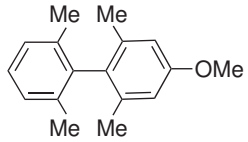
IR (KBr): 2917, 2856, 2360, 1717, 1613, 1464, 1376, 1163, 1035, 850, 769 cm^{-1}.

MS (EI) m/z (relative intensity) 224 (58) [M^+], 194 (40), 179 (44), 165 (18), 96 (13).

HR-MS (ESI): m/z calcd for $C_{17}H_{21}$ 225.1565, found 225.1565.

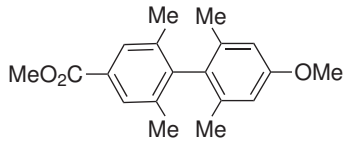
The analytical data were in accordance with those reported in the literature.[22]

Synthesis of 4-methoxy-2,2′,6,6′-tetramethylbiphenyl (9t)



The representative procedure B was followed using 4-methoxy-2,6-dimethylphenylboronic acid (**41e**) (135 mg, 0.75 mmol), 2-chloro-1,3-dimethyl benzene (**8s**) (70 mg, 0.50 mmol), [$Pd_2(dba)_3$] (18.3 mg, 0.02 mmol), **15a** (35.6 mg, 0.08 mmol) and CsF (228 mg, 1.50 mmol) at 110 °C. After 24 h, purification by chromatography (*n*-hexane/EtOAc: 150/1) yielded **9t** (61 mg, 51%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.19–7.08 (m, 3H), 6.69 (s, 2H), 3.83 (s, 3H), 1.90 (s, 6H), 1.87 (s, 6H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 158.2 (C_q), 139.7 (C_q), 136.7 (C_q), 136.1 (C_q), 132.5 (C_q), 127.3 (CH), 126.7 (CH), 112.7 (CH), 55.0 (CH_3), 20.1 (CH_3), 19.9 (CH_3).
IR (KBr): 2921, 2735, 1607, 1465, 1377, 1316, 1266, 1193, 1154, 1070, 933, 772 cm^{-1}.
MS (EI) m/z (relative intensity) 240 (100) [M^+], 225 (40), 210 (16), 195 (6), 165 (6), 120 (2), 105 (2).
HR-MS (ESI): m/z calcd for $C_{17}H_{20}O$+Na^+ 263.1406, found 263.1407.
The analytical data were in accordance with those reported in the literature.[24]

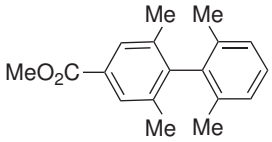
Synthesis of 4′-methoxy-2,2′,6,6′-tetramethylbiphenyl-4-carboxylic acid methylester (9u)



The representative procedure B was followed using 4-methoxy-2,6-dimethylphenylboronic acid (**41e**) (135 mg, 0.75 mmol), 4-chloro-3,5-dimethylbenzoic acid methylester (**8q**) (99 mg, 0.50 mmol), [$Pd_2(dba)_3$] (18.3 mg, 0.02 mmol), **15a** (35.6 mg, 0.08 mmol) and CsF (228 mg, 1.50 mmol) at 110 °C. After 24 h, purification by chromatography (*n*-pentane/MTBE: 30/1) yielded **9u** (79 mg, 53%) as a colorless solid. m.p. 111–113 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.80 (s, 2H), 6.69 (s, 2H), 3.92 (s, 3H), 3.82 (s, 3H), 1.94 (s, 6H), 1.84 (s, 6H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 167.5 (C_q), 158.5 (C_q), 145.1 (C_q), 136.7 (C_q), 136.7 (C_q), 136.2 (C_q), 131.5 (C_q), 128.5 (CH), 112.9 (CH), 55.0 (CH_3), 52.0 (CH_3), 19.9 (CH_3), 19.8 (CH_3).
IR (KBr): 2948, 1784, 1723, 1608, 1438, 1323, 1257, 1155, 1068, 1014, 898, 773 cm^{-1}.

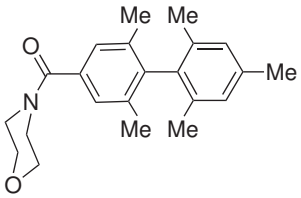
MS (EI) m/z (relative intensity) 298 (100) [M^+], 267 (8), 224 (10), 209 (8), 133 (2).
HR-MS (ESI): m/z calcd for $C_{19}H_{22}O_3$+Na 321.1461, found 321.1469.

Synthesis of methyl 2,2′,6,6′-tetramethylbiphenyl carboxylate (9v)



The representative procedure B was followed using 2,6-dimethylphenyl boronic acid (**41d**) (112 mg, 0.75 mmol), 4-chloro-3,5-dimethylbenzoic acid methylester (**8q**) (99 mg, 0.50 mmol), [$Pd_2(dba)_3$] (18.3 mg, 0.02 mmol), **15a** (35.6 mg, 0.08 mmol) and CsF (228 mg, 1.50 mmol) at 110 °C. After 24 h, purification by chromatography (*n*-hexane/EtOAc: 50/1) yielded **9v** (66 mg, 49%) as a colorless solid. m.p. 87–89 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.81 (s, 2H), 7.22–7.10 (m, 3H), 3.93 (s, 3H), 1.94 (s, 6H), 1.87 (s, 6H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 167.5 (C_q), 145.2 (C_q), 139.0 (C_q), 136.1 (C_q), 134.8 (C_q), 128.6 (CH), 128.6 (C_q), 127.6 (CH), 127.2 (CH), 52.0 (CH_3), 19.8 (CH_3), 19.7 (CH_3).
IR (KBr): 2944, 2922, 1719, 1579, 1428, 1374, 1312, 1014, 763 cm^{-1}.
MS (EI) m/z (relative intensity) 268 (100) [M^+], 253 (30), 237 (44), 221 (12), 209 (30), 194 (34), 179 (26), 111 (8).
HR-MS (ESI): m/z calcd for $C_{18}H_{20}O_2$+H^+ 269.1536, found 269.1539.

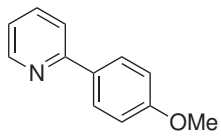
Synthesis of morpholino(2,2′,4′,6,6′-pentamethylbiphenyl-4-yl)methanone (9w)



The representative procedure B was followed using mesitylboronic acid (**41c**) (123 mg, 0.75 mmol), (4-chloro-3,5-dimethylphenyl) (morpholino) methanone (**8r**) (127 mg, 0.50 mmol), [$Pd_2(dba)_3$] (18.3 mg, 0.02 mmol), **15a** (35.6 mg, 0.08 mmol) and CsF (228 mg, 1.50 mmol) at 110 °C. After 24 h, purification by chromatography (*n*-pentane/MTBE: 1/1) yielded **9w** (96 mg, 57%) as a yellow solid. m.p. 166–168 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.15 (s, 2H), 6.94 (s, 2H), 3.73 (s_{br}, 8H), 2.33 (s, 3H), 1.91 (s, 6H), 1.84 (s, 6H).
^{13}C-NMR (75 MHz, CD_3OD) δ = 170.9 (C_q), 142.0 (C_q), 136.5 (C_q), 136.4 (C_q), 136.0 (C_q), 134.9 (C_q), 133.6 (C_q), 128.4 (CH), 126.1 (CH), 67.0 (2 x CH_2), 21.1 (CH_3), 19.9

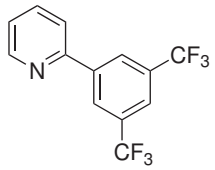
(CH_3), 19.7 (CH_3).
IR (KBr): 2954, 2858, 1646, 1564, 1429, 1304, 1227, 1117, 1001, 885, 769 cm^{-1}.
MS (EI) m/z (relative intensity) 337 (40) [M^+], 251 (100), 208 (12), 193 (16), 132 (8), 56 (15), 41 (4).
HR-MS (ESI): m/z calcd for $C_{22}H_{28}NO_2$ 338.2115, found 338.2115.

Synthesis of 2-(4-methoxyphenyl)pyridine (26aa)



The representative procedure C was followed using **24a** (205 mg, 0.75 mmol), 4-bromoanisole (**2c**) (94 mg, 0.50 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **14d** (11.7 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-hexane/EtOAc: 10/1) yielded **26aa** (59 mg, 64%) as a yellow solid. m.p. 53–55 °C, Lit.:[112] 53–54 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.63 (m, 1H), 7.93 (d, J = 8.5 Hz, 2H), 7.73–7.61 (m, 2H), 7.14 (m, 1H), 7.04–6.93 (m, 2H), 3.84 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 160.6 (C_q), 157.3 (C_q), 149.7 (CH), 136.8 (CH), 132.2 (C_q), 128.3 (CH), 121.5 (CH), 119.9 (CH), 114.3 (CH), 55.5 (CH_3).
IR (KBr): 2839, 1610, 1589, 1516, 1467, 1249, 1040, 841, 783, 746 cm^{-1}.
MS (EI) m/z (relative intensity) 185 (100) [M^+], 170 (21), 142 (33), 115 (4), 89 (3).
HR-MS (ESI): m/z calcd for $C_{12}H_{11}NO$ 185.0841, found 185.0835.
The spectral data were in accordance with those reported in the literature.[119]

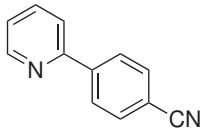
Synthesis of 2-{3,5-bis(trifluoromethyl)phenyl}pyridine (26ab)



The representative procedure C was followed, using **24a** (205 mg, 0.75 mmol), 3,5-bis(trifluoromethyl)bromobenzene (**2d**) (159 mg, 0.54 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **14d** (11.7 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-pentane/MTBE: 20/1 → 7/1) yielded **26ab** (123 mg, 78%) as a colorless solid. m.p. 48–49 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.78–8.71 (m, 1H), 8.48 (s, 2H), 7.91 (s, 1H), 7.88–7.77 (m, 2H), 7.35 (m, 1H).

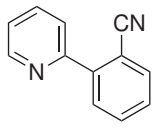
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 154.1 (C_q), 150.1 (CH), 141.3 (C_q), 137.2 (CH), 132.1 (C_q, $^2J_{C–F}$ = 34 Hz), 128.8 (C_q), 126.9 (CH, $^3J_{C–F}$ = 3 Hz), 123.6 (CH), 123.4 (C_q, $^1J_{C–F}$ = 272 Hz), 122.4 (CH, $^3J_{C–F}$ = 4 Hz), 120.6 (CH), 117.9 (C_q).
^{19}F-NMR (282 MHz, $CDCl_3$) δ = –62.9 (s).
IR (KBr): 3749, 2927, 2644, 1591, 1573, 1455, 1382, 1279, 1173, 1136, 1074, 785 cm^{-1}
MS (EI) m/z (relative intensity) 291 (100) [M^+], 252 (10), 202 (12), 83 (28), 71 (34), 57 (66), 43 (64), 41 (14).
HR-MS (EI) m/z calcd for $C_{13}H_6F_6N+H^+$ 292.0555, found 292.0557.
The spectral data were in accordance with those reported in the literature.[27]

Synthesis of 2-(4-cyanophenyl)pyridine (26ac)



The representative procedure C was followed using **24a** (205 mg, 0.75 mmol), 4-bromobenzonitrile (**2e**) (91 mg, 0.50 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **14d** (11.7 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-hexane/EtOAc: 10/1 → 5/1) yielded **26ac** (78 mg, 87%) as a colorless solid. m.p.: 92–94 °C. Lit.:[27] 91–92 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.72 (dt, J = 4.9, 1.4 Hz, 1H), 8.46 (s, 2H), 7.89 (s, 1H), 7.86– 7.75 (m, 3H), 7.32 (ddd, J = 6.7, 4.8, 2.1 Hz, 1H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 155.1 (C_q), 150.0 (CH), 143.4 (C_q), 137.0 (CH), 132.5 (CH), 127.4 (CH), 123.3 (CH), 120.9 (CH), 118.7 (C_q), 112.3 (C_q).
IR (KBr): 3853, 3744, 2987, 2361, 1653, 1559, 1540, 1506, 1420 cm^{-1}.
MS (EI) m/z (relative intensity) 180 (100) [M^+], 152 (100), 127 (5), 90 (4), 51 (10).
HR-MS (EI) m/z calcd for $C_{11}H_9N_2+H^+$ 181.0760, found 181.0761.
The spectral data were in accordance with those reported in the literature.[27]

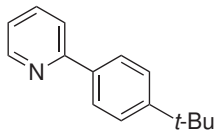
Synthesis of 2-(2-cyanophenyl)pyridine (26ad)



The representative procedure C was followed, using **24a** (205 mg, 0.75 mmol), 2-bromobenzonitrile (**2f**) (91 mg, 0.50 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **14d** (11.7 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-hexane/EtOAc: 10/1 → 5/1 → 4/1) yielded **26ad** (59 mg, 80%) as a colorless oil.

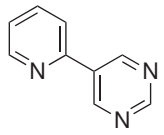
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.77 (ddd, J = 4.8, 1.7, 1.0 Hz, 1H), 7.88–7.73 (m, 4H), 7.69 (td, J = 7.7, 1.3 Hz, 1H), 7.50 (td, J = 7.7, 1.3 Hz, 1H), 7.39–7.29 (m, 1H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 155.2 (C_q), 149.9 (CH), 143.4 (C_q), 136.8 (CH), 134.1 (CH), 132.8 (CH), 130.0 (CH), 128.7 (CH), 123.3 (CH), 123.2 (CH), 118.7 (C_q), 111.0 (C_q).
IR (KBr): 3478, 2922, 2226, 1587, 1471, 1428, 1095, 762 cm^{-1}.
MS (EI) m/z (relative intensity) 180 (100) [M^+], 152 (10), 127 (5), 51 (10), 43 (8).
HR-MS (EI) m/z calcd for $C_{11}H_9N_2$+H^+ 181.0760, found 181.0760.
The spectral data were in accordance with those reported in the literature.[27]

Synthesis of 2-(4-*tert*-butylphenyl)pyridine (26ae)



The representative procedure C was followed, using **24a** (205 mg, 0.75 mmol), 4-*tert*-butylbromobenzene (**2g**) (118 mg, 0.55 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **14d** (11.7 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-hexane/EtOAc: 10/1) yielded **26ae** (71 mg, 61%) as a yellow oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.69 (dt, J = 4.8, 1.5 Hz, 1H), 7.94 (d, J = 8.8 Hz, 2H), 7.74–7.70 (m, 2H), 7.51 (d, J = 8.8 Hz, 2H), 7.21 (m, 1H), 1.38 (s, 9H).
^{13}C-NMR (126 MHz, $CDCl_3$) δ = 157.3 (C_q), 152.0 (C_q), 149.4 (C_q), 136.5 (CH), 136.5 (CH), 126.5 (CH), 125.6 (CH), 121.7 (CH), 120.2 (CH), 34.7 (C_q), 31.3 (CH_3).
IR (ATR): 2961, 2866, 1717, 1587, 1464, 1432, 1269, 1113, 844, 781 cm^{-1}.
MS (EI) m/z (relative intensity) 211 (22) [M^+], 196 (100), 83 (22), 78 (12), 57 (16).
HR-MS (EI) m/z calcd for $C_{15}H_{16}N$+H^+ 212.1434, found 212.1434.
The spectral data were in accordance with those reported in the literature.[120]

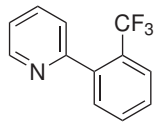
Synthesis of 5-(pyridin-2-yl)pyrimidine (26af)



The representative procedure C was followed, using **24a** (205 mg, 0.75 mmol), 5-bromopyrimidine (**2h**) (79 mg, 0.50 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **14d** (11.7 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (MTBE/Et_3N: 10/1) yielded **26af** (64 mg, 81%) as a colorless solid. m.p. 127–129 °C. Lit.:[27] 129–130 °C.

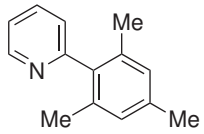
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 9.29 (s, 2H), 9.21 (s, 1H), 8.70 (d, J = 4.2 Hz, 1H), 7.84–7.68 (m, 2H), 7.31 (ddd, J = 7.4, 4.8, 1.3 Hz, 1H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 158.5 (CH), 154.9 (CH), 151.8 (C_q), 150.3 (CH), 137.1 (CH), 132.2 (C_q), 123.5 (CH), 120.4 (CH).
IR (KBr): 3434, 2364, 1588, 1572, 1481, 1408, 1290, 1184, 1018, 793 cm^{-1}.
MS (EI) m/z (relative intensity) 157 (100) [M$^+$], 130 (56), 104 (12), 79 (80), 50 (18).
HR-MS (EI) m/z calcd for $C_9H_7N_3$+H$^+$ 158.0713, found 158.0718.
The spectral data were in accordance with those reported in the literature.[27]

Synthesis of 2-{2-(trifluoromethyl)phenyl}pyridine (26ag)



The representative procedure C was followed, using **24a** (205 mg, 0.75 mmol), 2-bromobenzotrifluoride (**2i**) (129 mg, 0.57 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **14d** (11.7 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-hexane/EtOAc: 10/1 → 7/1) yielded **26ag** (55 mg, 43%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.69 (dq, J = 7.6, 0.8 Hz, 1H), 7.75 (td, J = 7.8, 1.8 Hz, 2H), 7.62 (t, J = 7.1 Hz, 1H), 7.55–7.49 (m, 2H), 7.43 (d, J = 7.8 Hz, 1H), 7.31 (ddd, J = 7.6, 4.9, 1.1 Hz, 1H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 157.8 (C_q), 149.1 (CH), 140.0 (C_q), 135.9 (CH), 131.5 (CH), 131.5 (CH), 128.3 (CH), 128.2 (C_q, $^2J_{C–F}$ = 30 Hz), 126.2 (CH, $^2J_{C–F}$ = 5 Hz), 124.0 (C_q, $^1J_{C–F}$ = 274 Hz), 123.9 (CH, $^3J_{C–F}$ = 2 Hz), 122.5 (CH)
^{19}F-NMR (282 MHz, $CDCl_3$) δ = –56.7.
IR (ATR): 2955, 2917, 2848, 1737, 1462, 1377, 1028, 798 cm^{-1}.
MS (EI) m/z (relative intensity) 223 (100) [M$^+$], 203 (48), 154 (40), 123 (75), 95 (20).
HR-MS (ESI) m/z calcd for $C_{12}H_8F_3N$+H$^+$ 224.0682, found 224.0681.
The spectral data were in accordance with those reported in the literature.[121]

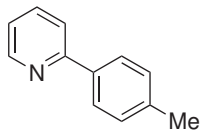
Synthesis of 2-(2,4,6-trimethylphenyl)pyridine (26ah)



The representative procedure C was followed, using **24a** (205 mg, 0.75 mmol), 2-bromomesitylene (**2j**) (118 mg, 0.59 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **14d** (11.7 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography

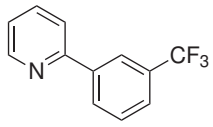
(*n*-hexane/EtOAc: 10/1 → 7/1 → 5/1) yielded **26ah** (35 mg, 30%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.71 (d, J = 4.1, 1H), 7.74 (dd, J = 7.6, 7.6 Hz, 1H), 7.26–7.21 (m, 2H), 6.93 (s, 2H), 2.32 (s, 3H), 2.01 (s, 6H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 160.0 (C_q), 149.6 (CH), 137.6 (C_q), 137.3 (C_q), 136.2 (CH), 135.6 (C_q), 128.2 (CH), 124.7 (CH), 121.5 (CH), 21.1 (CH_3), 20.1 (CH_3).
MS (EI) m/z (relative intensity) 196 (100) [M-H$^+$], 180 (8), 91 (2), 43 (4).
HR-MS (EI) m/z calcd for $C_{14}H_{15}N$+H$^+$ 198.1277, found 198.1277.
The spectral data were in accordance with those reported in the literature.[122]

Synthesis of 2-(4-methylphenyl)pyridine (26ai)



The representative procedure C was followed, using **24a** (205 mg, 0.75 mmol), 4-bromotoluene (**2k**) (101 mg, 0.59 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **14d** (11.7 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-pentane/MTBE: 10/1) yielded **26ai** (65 mg, 65%) as a yellow oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.68 (d, J = 5.2 Hz, 1H), 7.89 (d, J = 8.1 Hz, 2H), 7.77–7.67 (m, 2H), 7.28 (d, J = 8.1 Hz, 2H), 7.20 (m, 1H), 2.41 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 157.5 (C_q), 149.6 (CH), 138.9 (C_q), 136.6 (CH), 136.6 (C_q), 129.5 (CH), 126.8 (CH), 121.8 (CH), 120.2 (CH), 21.2 (CH_3).
IR (KBr): 3635, 3052, 2922, 2366, 1615, 1589, 1467, 1434, 1299, 1185, 1017, 774 cm^{-1}
MS (EI) m/z (relative intensity) 169 (100) [M$^+$], 154 (9), 97 (13), 57 (27), 43 (22).
HR-MS (EI) m/z calcd for $C_{12}H_{11}N$ 169.0891, found 169.0895.
The spectral data were in accordance with those reported in the literature.[110]

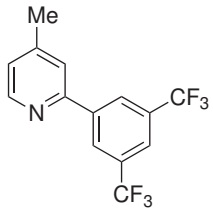
Synthesis of 2-{3-(trifluoromethyl)phenyl}pyridine (26aj)



The representative procedure C was followed, using **24a** (205 mg, 0.75 mmol), 3-bromobenzotrifluoride (**2l**) (123 mg, 0.55 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **14d** (11.7 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-pentane/MTBE: 20/1) yielded **26aj** (85 mg, 69%) as a yellow oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.70 (m, 1H), 8.27 (m, 1H), 8.15 (dm, J = 7.7 Hz, 1H), 7.80–7.70 (m, 2H), 7.66–7.53 (m, 2H), 7.25 (ddd, J = 6.7, 4.8, 2.1 Hz, 1H).

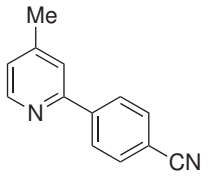
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 155.8 (C_q), 149.9 (CH), 140.1 (C_q), 137.0 (CH), 131.2 ($^2J_{C–F}$ = 32 Hz, C_q), 130.0 (CH), 129.2 (CH), 125.5 ($^3J_{C–F}$ = 4 Hz, CH), 124.1 ($^1J_{C–F}$ = 272 Hz, C_q), 123.8 (CH), 122.8 ($^3J_{C–F}$ = 4 Hz, CH), 120.6 (CH).
^{19}F-NMR (282 MHz, $CDCl_3$) δ = –62.6 (s).
IR (KBr): 3055, 3010, 1586, 1464, 1437, 1417, 1333, 1261, 1118, 774 cm^{-1}.
MS (EI) m/z (relative intensity) 223 (100) [M^+], 203 (28), 154 (48), 127 (10), 51 (12).
HR-MS (EI) m/z calcd for $C_{12}H_8F_3N$ 223.0609, found 223.0612.
The spectral data were in accordance with those reported in the literature.[27]

Synthesis of 2-{3,5-Bis(trifluoromethyl)phenyl}-4-methylpyridine (26ak)



The representative procedure C was followed, using **24b** (216 mg, 0.75 mmol), 3,5-bis(trifluoromethyl) bromobenzene (**2d**) (155 mg, 0.53 mmol), [$Pd_2(dba)_3$] (6.9 mg, 0.0075 mmol), **14d** (17.5 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-pentane/MTBE: 10/1) yielded **26ak** (109 mg, 67%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.59 (d, J = 4.9 Hz, 1H), 8.46 (s, 2H), 7.90 (s, 1H), 7.62 (m, 1H), 7.16 (dm, J = 5.0 Hz, 1H), 2.46 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 154.0 (C_q), 149.9 (CH), 148.5 (C_q), 141.5 (C_q), 132.0 (C_q, $^2J_{C–F}$ = 33 Hz), 127.0 (C_q, $^1J_{C–F}$ = 272 Hz), 126.9 (CH, $^3J_{C–F}$ = 4 Hz), 124.5 (CH), 122.3 (CH, $^3J_{C–F}$ = 4 Hz), 121.6 (CH), 21.2 (CH_3).
^{19}F-NMR (282 MHz, CDC_3) δ = –62.8.
IR (ATR): 2962, 2928, 1604, 1449, 1367, 1275, 1169, 1125, 898, 826 cm^{-1}.
MS (EI) m/z (relative intensity) 305 (100) [M^+], 290 (42), 236 (32), 216 (12), 167 (16), 65 (10).
HR-MS (EI) m/z calcd for $C_{14}H_9F_6N$ 305.0639, found 305.0643.
The spectral data were in accordance with those reported in the literature.[123]

Synthesis of 4-(4-methylpyridin-2-yl)benzonitrile (26al)



The representative procedure C was followed, using **24b** (216 mg, 0.75 mmol), 4-bromobenzonitrile (**2e**) (91 mg, 0.50 mmol), [$Pd_2(dba)_3$] (6.9 mg, 0.0075 mmol), **14d** (17.5 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-pentane/MTBE: 10/1 → 2/1) yielded **26al** (55 mg, 57%) as a colorless solid. m.p. 112–114 °C.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.58 (d, J = 5.0 Hz, 1H), 8.10 (d, J = 8.8 Hz, 2H), 7.75 (d, J = 8.8 Hz, 2H), 7.58 (m, 1H), 7.14 (ddd, J = 5.0, 1.5, 0.7 Hz, 1H), 2.44 (s, 3H).

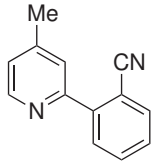
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 154.9 (C_q), 149.6 (CH), 148.1 (C_q), 143.5 (C_q), 132.3 (CH), 127.3 (CH), 124.2 (CH), 121.8 (CH), 118.7 (C_q), 112.1 (C_q), 21.1 (CH_3)

IR (KBr): 3035, 2225, 1603, 1378, 1105, 992, 819 cm^{-1}.

MS (EI) m/z (relative intensity) 194 (100) [M^+], 179 (32), 166 (10), 140 (8), 51 (5).

HR-MS (EI) m/z calcd for $C_{13}H_{10}N_2$ 194.0844, found 194.0840

Synthesis of 2-(4-methylpyridin-2-yl)benzonitrile (26am)



The representative procedure C was followed, using **24b** (216 mg, 0.75 mmol), 2-bromobenzonitrile (**2f**) (91 mg, 0.50 mmol), [$Pd_2(dba)_3$] (6.9 mg, 0.0075 mmol), **14d** (17.5 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-pentane/MTBE: 10/1 → 2/1) yielded **26am** (52 mg, 54%) as a yellow solid. m.p. 55–56 °C.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.62 (d, J = 5.0 Hz, 1H), 7.85–7.74 (m, 2H), 7.68 (td, J = 7.6, 1.4 Hz, 1H), 7.58 (m, 1H), 7.49 (td, J = 7.6, 1.3 Hz, 1H), 7.17 (md, J = 5.0 Hz, 1H), 2.45 (s, 3H).

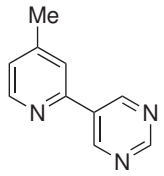
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 155.1 (C_q), 149.6 (CH), 148.0 (C_q), 143.7 (C_q), 134.0 (CH), 132.7 (CH), 129.9 (CH), 128.6 (CH), 124.3 (CH), 124.2 (CH), 118.7 (C_q), 111.1 (C_q), 21.2 (CH_3).

IR (ATR): 3148, 2221, 1609, 1557, 1428, 1189, 1002, 872, 754 cm^{-1}.

MS (EI) m/z (relative intensity) 194 (100) [M^+], 179 (10), 166 (12), 140 (8), 102 (5), 65 (6), 43 (15).

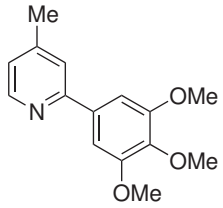
HR-MS (EI) m/z calcd for $C_{13}H_{10}N_2$ 194.0844, found 194.0840.

Synthesis of 5-(4-methylpyridin-2-yl)pyrimidine (26an)



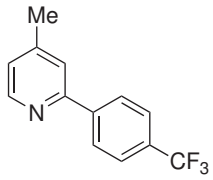
The representative procedure C was followed, using **24b** (216 mg, 0.75 mmol), 5-bromopyrimidine (**2h**) (79 mg, 0.50 mmol), [$Pd_2(dba)_3$] (6.9 mg, 0.0075 mmol), **14d** (17.5 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (MTBE/Et_3N: 10/1) yielded **26an** (54 mg, 63%) as an off-white solid. m.p. 72–73 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 9.28 (s, 2H), 9.23 (m, 1H), 8.58 (m, 1H), 7.55 (s, 1H), 7.15 (m, 1H), 2.43 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 158.5 (CH), 155.1 (CH), 151.9 (C_q), 150.1 (CH), 148.4 (C_q), 132.5 (C_q), 124.5 (CH), 121.5 (CH), 21.2 (CH_3).
IR (KBr): 3047, 2856, 1602, 1439, 1207, 1106, 829, 717 cm^{-1}.
MS (EI) m/z (relative intensity) 171 (100) [M^+], 144 (76), 118 (20), 93 (88), 65 (16).
HR-MS (EI) m/z calcd for $C_{10}H_9N_3$ 171.0796, found 171.0792.

Synthesis of 4-methyl-2-(3,4,5-trimethoxyphenyl)pyridine (26ao)



The representative procedure C was followed, using **24b** (216 mg, 0.75 mmol), 3,4,5-(trimethoxy)bromobenzene (**2m**) (124 mg, 0.50 mmol), [$Pd_2(dba)_3$] (6.9 mg, 0.0075 mmol), **14d** (17.5 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-pentane/MTBE: 5/1 → 1/1) yielded **26ao** (28 mg, 22%) as a colorless solid. m.p. 90–92 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.53 (d, J = 5.0 Hz, 1H), 7.49 (s, 1H), 7.22 (s, 2H), 7.05 (d, J = 5.0 Hz, 1H), 3.97 (s, 6H), 3.90 (s, 3H), 2.42 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 157.0 (C_q), 153.5 (C_q), 149.3 (CH), 147.8 (C_q), 139.0 (C_q), 135.2 (C_q), 123.1 (CH), 121.3 (CH), 104.2 (CH), 60.9 (CH_3), 56.3 (CH_3), 21.2 (CH_3). **IR** (ATR): 2922, 1586, 1554, 1505, 1416, 1335, 1124, 1005, 813 cm^{-1}.
MS (EI) m/z (relative intensity) 259 (100) [M^+], 244 (58), 216 (26), 201 (23), 186 (40), 130 (21), 43 (13).
HR-MS (EI) m/z calcd for $C_{15}H_{17}NO_3$ 259.1208, found 259.1212.

Synthesis of 4-methyl-2-[4-(trifluoromethyl)phenyl]pyridine (26ap)



The representative procedure C was followed, using **24b** (216 mg, 0.75 mmol), 4-bromobenzotrifluoride (**2p**) (113 mg, 0.50 mmol), [$Pd_2(dba)_3$] (6.9 mg, 0.0075 mmol), **14d** (17.5 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-pentane/MTBE: 20/1) yielded **26ap** (84 mg, 71%) as a colorless solid. m.p. 91–93 °C.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.57 (d, J = 5.0 Hz, 1H), 8.09 (d, J = 8.7 Hz, 2H), 7.71 (d, J = 8.7 Hz, 2H), 7.57 (d, J = 0.7 Hz, 1H), 7.11 (d, J = 5.0 Hz, 1H), 2.43 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$) δ = 155.7 (C_q), 149.6 (CH), 148.0 (C_q), 142.8 (C_q) , 130.6 (C_q, $^2J_{C–F}$ = 32 Hz), 127.1 (CH), 125.6 (CH; $^3J_{C–F}$ = 4 Hz), 124.0 (C_q, $^1J_{C–F}$ = 272 Hz), 123.9 (CH), 121.8 (CH), 21.2 (CH_3).

^{19}F-NMR (282 MHz, $CDCl_3$) δ = –62.6 (s).

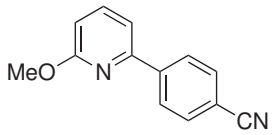
IR (KBr): 2919, 1604, 1324, 1163, 1103, 1070, 823, 729 cm^{-1}.

MS (EI) m/z (relative intensity) 237 (100) [M^+], 222 (25), 168 (33), 97 (8), 69 (15), 57 (22), 43 (75).

HR-MS (EI) m/z calcd for $C_{13}H_{10}F_3N$ 237.0765, found 237.0765

The spectral data were in accordance with those reported in the literature.[124]

Synthesis of 4-(6-methoxypyridin-2-yl)benzonitrile (26aq)



The representative procedure C was followed, using **24c** (227 mg, 0.75 mmol), 4-bromobenzonitrile (**2e**) (91 mg, 0.50 mmol), [$Pd_2(dba)_3$] (6.9 mg, 0.0075 mmol), **14d** (17.5 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-pentane/MTBE: 5/1) yielded **26aq** (67 mg, 64%) as a yellow solid. m.p. 82–85 °C.

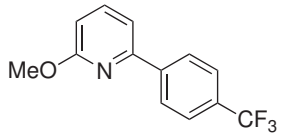
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.14 (d, J = 8.4 Hz, 2H), 7.73 (d, J = 8.4 Hz, 2H), 7.67 (dd, J = 7.8, 7.5 Hz, 1H), 7.37 (d, J = 7.4 Hz, 1H), 6.77 (d, J = 8.2 Hz, 1H), 4.03 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$) δ = 163.9 (C_q), 152.3 (C_q), 143.1 (C_q), 139.3 (CH), 132.4 (CH), 127.1 (CH), 118.9 (C_q), 113.5 (CH), 112.1 (C_q), 110.9 (CH), 53.3 (CH_3).

IR (ATR): 2923, 2225, 1737, 1604, 1578, 1510, 1464, 1325, 1157, 1026, 790 cm^{-1}.

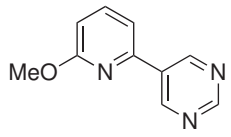
MS (EI) m/z (relative intensity) 209 (100) [M-H$^+$], 179(55), 152 (12), 140 (10), 127 (10), 75 (6), 43 (6).
HR-MS (EI) m/z calcd for $C_{13}H_{10}N_2O$ 210.0793, found 210.0791.

Synthesis of 6-methoxy-2-{4-(trifluoromethyl)phenyl}pyridine (26ar)



The representative procedure C was followed, using **24c** (227 mg, 0.75 mmol), 4-bromobenzotrifluoride (**2p**) (113 mg, 0.50 mmol), [$Pd_2(dba)_3$] (6.9 mg, 0.0075 mmol), **14d** (17.5 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-pentane/MTBE: 50/1) yielded **26ar** (86 mg, 68%) as a yellow oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.13 (d, J = 8.2 Hz, 2H), 7.72 (d, J = 8.2 Hz, 2H), 7.67 (d, J = 7.5 Hz, 1H), 7.41 (d, J = 8.0 Hz, 1H), 6.74 (d, J = 7.5 Hz, 1H), 2.62 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 163.8 (C_q), 153.0 (C_q), 142.3 (C_q), 139.2 (CH), 130.7 ($^2J_{C–F}$ = 33 Hz, C_q), 127.1 (CH), 125.4 ($^3J_{C–F}$ = 4 Hz, CH), 124.2 ($^1J_{C–F}$ = 272 Hz, C_q), 113.2 (CH), 110.3 (CH), 53.2 (CH_3).
^{19}F-NMR (282 MHz, $CDCl_3$) δ = –62.5 (s).
IR (KBr): 2986, 2946, 1625, 1548, 1397, 1248, 1116, 1054, 987, 798, 739 cm^{-1}.
MS (EI) m/z (relative intensity) 253 (100) [M$^+$], 223 (20), 202 (5), 154 (20), 51 (5).
HR-MS (EI) m/z calcd for $C_{13}H_{10}NOF_3$ 253.0714, found 253.0719.

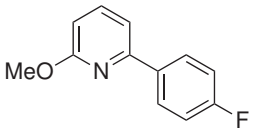
Synthesis of 5-(6-methoxypyridin-2-yl)pyrimidine (26as)



The representative procedure C was followed, using **24c** (227 mg, 0.75 mmol), 5-bromopyrimidine (**2h**) (79 mg, 0.50 mmol), [$Pd_2(dba)_3$] (6.9 mg, 0.0075 mmol), **14d** (17.5 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-pentane/MTBE: 1/1) yielded **26as** (77 mg, 82%) as a colorless solid.
m.p. 123–125 °C. Lit.:[125] 120 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 9.34 (s, 2H), 9.22 (s, 1H), 7.69 (dd, J = 7.8, 7.5 Hz, 1H), 7.36 (d, J = 7.4 Hz, 1H), 6.79 (d, J = 8.3 Hz, 1H), 4.02 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 164.2 (C_q), 158.4 (CH), 154.9 (CH), 149.1 (C_q), 139.5 (CH), 132.0 (C_q), 112.9 (CH), 111.3 (CH), 53.4 (CH_3).

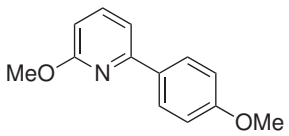
IR (KBr): 3071, 3016, 1981, 1704, 1604, 1470, 1400, 1262, 1016, 798 cm^{-1}.
MS (EI) m/z (relative intensity) 187 (100) [M^+], 159 (45), 130 (32), 76 (26), 43 (43).
HR-MS (EI) m/z calcd for $C_{10}H_9N_3O$ 187.0746, found 187.0755.
The spectral data were in accordance with those reported in the literature.[125]

Synthesis of 2-(4-fluorophenyl)-6-methoxypyridine (26at)



The representative procedure C was followed, using **24c** (227 mg, 0.75 mmol), 1-bromo-4-fluorobenzene (**2q**) (55 μL, 0.50 mmol), [$Pd_2(dba)_3$] (6.9 mg, 0.0075 mmol), **14d** (17.5 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-pentane/MTBE: 50/1) yielded **26at** (67 mg, 66%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.07–8.00 (m, 2H), 7.62 (dd, J = 7.4, 7.4 Hz, 1H), 7.29 (dd, J = 7.4, 0.6 Hz, 1H), 7.18–7.10 (m, 2H), 6.69 (dd, J = 7.4, 0.6 Hz, 1H), 4.02 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 163.7 (C_q), 163.4 ($^1J_{C–F}$ = 247 Hz, C–F), 153.6 (C_q), 139.2 (CH), 135.2 ($^4J_{C–F}$ = 3 Hz, C_q), 128.5 ($^3J_{C–F}$ = 9 Hz, CH), 115.5 ($^2J_{C–F}$ = 21 Hz, CH), 112.3 (CH), 109.1 (CH), 53.1 (CH_3).
^{19}F-NMR (282 MHz, $CDCl_3$) δ = –113.3 (m).
IR (KBr): 3065, 2984, 1625, 1603, 1575, 1438, 1397, 1250, 1123, 1061, 973, 751 cm^{-1}.
MS (EI) m/z (relative intensity) 203 (100) [M^+], 190 (40), 174 (40), 158 (5), 146 (5), 133 (10), 86 (5), 73 (5).
HR-MS (EI) m/z calcd for $C_{12}H_{10}FN+H^+$ 204.0819, found 204.0819.
The spectral data were in accordance with those reported in the literature.[126]

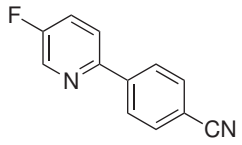
Synthesis of 2-methoxy-6-(4-methoxyphenyl)pyridine (26au)



The representative procedure C was followed, using **24c** (227 mg, 0.75 mmol), 4-bromoanisole (**2c**) (104 mg, 0.56 mmol), [$Pd_2(dba)_3$] (6.9 mg, 0.0075 mmol), **14d** (17.5 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-pentane/MTBE: 5/1 → 1/1) yielded **26au** (75 mg, 62%) as a colorless solid. m.p. 118–119 °C. Lit.:[27] 120–121 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.00 (d, J = 8.9 Hz, 2H), 7.58 (dd, J = 7.6, 7.6 Hz,

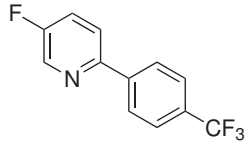
1H), 7.25 (d, J = 7.5 Hz, 1H), 6.97 (d, J = 8.9 Hz, 2H), 6.63 (d, J = 7.6 Hz, 1H), 4.03 (s, 3H), 3.85 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 163.6 (C_q), 160.3 (C_q), 154.4 (C_q), 139.0 (CH), 131.7 (C_q), 127.9 (CH), 113.9 (CH), 111.8 (CH), 108.2 (CH), 55.3 (CH_3), 53.1 (CH_3).
IR (KBr): 2948, 2842, 1572, 1461, 1241, 1024, 790 cm^{-1}.
MS (EI) m/z (relative intensity) 215 (100) [M$^+$], 186 (22), 170 (35), 157 (12), 128 (12), 115 (13), 102 (10), 43 (16).
HR-MS (EI) m/z calcd for $C_{13}H_{13}NO_2$ 215.0946, found 215.0936.
The spectral data were in accordance with those reported in the literature.[27]

Synthesis of 4-(5-fluoropyridin-2-yl)benzonitrile (26av)



The representative procedure C was followed, using **24d** (218 mg, 0.75 mmol), 4-bromobenzonitrile (**2e**) (91 mg, 0.50 mmol), [$Pd_2(dba)_3$] (6.9 mg, 0.0075 mmol), **14d** (17.5 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-pentane/MTBE: 5/1) yielded **26av** (39 mg, 39%) as a yellow solid. m.p. 58–60 °C. Lit.:[27] 61–62 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.58 (d, J = 2.9 Hz, 1H), 8.07 (d, J = 8.7 Hz, 2H), 7.80–7.74 (m, 1H), 7.76 (d, J = 8.7 Hz, 2H), 7.52 (ddd, J = 8.7, 7.9, 2.9 Hz, 1H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 159.3 (C_q, $^1J_{C–F}$ = 258 Hz), 151.4 (C_q, $^4J_{C–F}$ = 4 Hz), 142.3 (C_q), 138.4 (CH, $^2J_{C–F}$ = 24 Hz), 132.6 (CH), 127.2 (CH), 123.8 (CH, $^2J_{C–F}$ = 19 Hz), 121.8 (CH, $^3J_{C–F}$ = 4 Hz), 118.7 (C_q), 112.4 (C_q).
^{19}F-NMR (282 MHz, $CDCl_3$) δ = –127.1 (m).
IR (ATR): 3044, 2226, 1734, 1582, 1264, 1014, 834 cm^{-1}.
MS (EI) m/z (relative intensity) 198 (100) [M$^+$], 171 (22), 99 (14), 76 (12), 50 (13).
HR-MS (EI) m/z calcd for $C_{12}H_7FN_2$ 198.0593, found 198.0602.
The spectral data were in accordance with those reported in the literature.[27]

Synthesis of 5-fluoro-2-{4-(trifluoromethyl)phenyl}pyridine (26aw)



The representative procedure C was followed, using **24d** (218 mg, 0.75 mmol), 4-bromobenzotrifluoride (**2p**) (125 mg, 0.56 mmol), [$Pd_2(dba)_3$] (6.9 mg, 0.0075 mmol), **14d** (17.5

mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-pentane/MTBE: 20/1) yielded **26aw** (52 mg, 39%) as a yellow solid. m.p. 46–48 °C.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.57 (d, J = 2.9 Hz, 1H), 8.06 (d, J = 8.2 Hz, 2H), 7.77 (m, 1H), 7.72 (d, J = 8.2 Hz, 2H), 7.50 (m, 1H).

^{13}C-NMR (75 MHz, $CDCl_3$) δ = 159.2 (C_q, $^1J_{C–F}$ = 258 Hz), 152.0 (C_q, $^4J_{C–F}$ = 4Hz), 141.6 (C_q), 138.1 (CH, $^2J_{C–F}$ = 24 Hz), 130.7 (C_q, $^2J_{C–F}$ = 32 Hz), 127.0 (CH), 125.7 (CH, $^3J_{C–F}$ = 4 Hz), 123.6 (CH, $^2J_{C–F}$ = 18 Hz), 124.0 (C_q, $^1J_{C–F}$ = 272 Hz), 121.6 (CH, $^3J_{C–F}$ = 4 Hz).

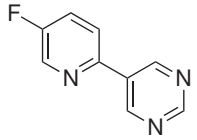
^{19}F-NMR (282 MHz, $CDCl_3$) δ = -62.6 (s), -128.0 (m).

IR (ATR): 3018, 2928, 1574, 1479, 1325, 1105, 825, 709 cm^{-1}.

MS (EI) m/z (relative intensity) 241 (100) [M^+], 222 (18), 172 (40), 145 (8), 43 (10).

HR-MS (EI) m/z calcd for $C_{12}H_7F_4N$ 241.0515, found 241.0518.

Synthesis of 5-(5-fluoropyridin-2-yl)pyrimidine (26ax)



The representative procedure C was followed, using **24d** (218 mg, 0.75 mmol), 5-bromopyrimidine (**2h**) (79 mg, 0.50 mmol), [$Pd_2(dba)_3$] (6.9 mg, 0.0075 mmol), **14d** (17.5 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-pentane/MTBE: 1/1) yielded **26ax** (31 mg, 35%) as a colorless solid.

m.p. 119–120 °C.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 9.29 (s, 2H), 9.25 (s, 1H), 8.60 (d, J = 2.8 Hz, 1H), 7.77 (ddd, J = 8.7, 4.2, 0.6 Hz, 1H), 7.57 (dd, J = 7.9, 2.9 Hz, 1H), 7.55 (ddd, J = 8.7, 7.9, 2.9 Hz, 1H).

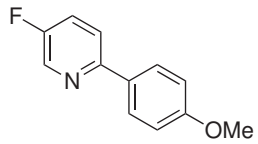
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 159.5 (C_q, $^1J_{C–F}$ = 259 Hz), 158.5 (CH), 154.8 (CH), 148.2 (C_q, $^4J_{C–F}$ = 4Hz), 138.9 (CH, $^2J_{C–F}$ = 24Hz), 131.5 (C_q), 124.0 (CH, $^2J_{C–F}$ = 19 Hz), 121.4 (CH, $^3J_{C–F}$ = 5 Hz). ^{19}F-NMR (282 MHz, $CDCl_3$) δ = –126.2 (m).

IR (KBr): 3058, 2961, 1578, 1557, 1485, 1440, 1230, 1014, 837, 644 cm^{-1}.

MS (EI) m/z (relative intensity) 175 (100) [M^+], 148 (65), 121 (42), 97 (75), 43 (38).

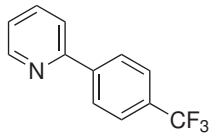
HR-MS (EI) m/z calcd for $C_9H_6FN_3$ 175.0546, found 175.0543.

Synthesis of 5-fluoro-2-(4′-methoxyphenyl)pyridine (26ay)



The representative procedure C was followed, using **24d** (218 mg, 0.75 mmol), 4-bromoanisole (**2c**) (106 mg, 0.57 mmol), [$Pd_2(dba)_3$] (6.9 mg, 0.0075 mmol), **14d** (17.5 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-pentane/MTBE: 10/1) yielded **26ay** (48 mg, 41%) as a yellow solid. m.p. 84–86 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.50 (d, J = 2.5 Hz, 1H), 7.88 (d, J = 8.5 Hz, 2H), 7.64 (m, 1H), 7.43 (m, 1H), 6.99 (d, J = 8.5 Hz, 2H), 3.86 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 160.3 (C_q), 158.4 (C_q, $^1J_{C–F}$ = 256 Hz), 153.4 (C_q, $^4J_{C–F}$ = 4 Hz), 137.5 (CH, $^2J_{C–F}$ = 23 Hz), 131.1 (C_q), 128.0 (CH), 123.4 (CH, $^2J_{C–F}$ = 19 Hz), 120.4 (CH, $^3J_{C–F}$ = 4 Hz), 114.1 (CH), 55.3 (CH_3).
^{19}F-NMR (282 MHz, $CDCl_3$) δ = –131.0 (m).
IR (KBr): 3014, 2968, 1605, 1456, 1222, 1044, 791 cm^{-1}.
MS (EI) m/z (relative intensity) 203 (100), 188 (38), 160 (66), 134 (10), 107 (8), 63 (6).
HR-MS (EI) m/z calcd for $C_{12}H_{10}FNO$ 203.0746, found 203.0742.

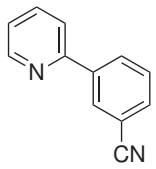
Synthesis of 2-{4-(trifluoromethyl)phenyl}pyridine (26az)



The representative procedure C was followed using **24a** (205 mg, 0.75 mmol), 4-chlorobenzotrifluoride (**8k**) (119 mg, 0.53 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **14d** (17.5 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-hexane/EtOAc: 10/1 → 5/1) yielded **26az** (59 mg, 50%) as a colorless solid. m.p. 70–72 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.73 (m, 1H), 8.11 (d, J = 8.2 Hz, 2H), 7.87–7.65 (m, 4H), 7.30 (ddd, J = 6.7, 4.8, 1.9 Hz, 1H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 155.8 (C_q), 149.9 (CH), 142.6 (C_q), 136.8 (CH), 130.9 ($^2J_{C–F}$ = 32 Hz, C_q), 127.1 (CH), 125.6 ($^3J_{C–F}$ = 4 Hz, CH), 124.2 ($^1J_{C–F}$ = 272 Hz, C_q), 122.9 (CH), 120.8 (CH).
^{19}F-NMR (282 MHz, $CDCl_3$): δ = –62.6 (s).
IR (KBr): 3430, 2362, 1616, 1588, 1568, 1468, 1330, 1156, 1108, 855, 783 cm^{-1}.
MS (EI) m/z (relative intensity) 223 (100) [M^+], 203 (12), 154 (30), 127 (3), 43 (2).

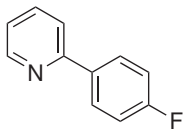
HR-MS (ESI) m/z calcd for $C_{12}H_8F_3N+H^+$ 224.0682, found 224.0682.
The spectral data were in accordance with those reported in the literature.[127]

Synthesis of 3-(pyridin-2-yl)benzonitrile (26ba)



The representative procedure C was followed, using **24a** (205 mg, 0.75 mmol), 3-chlorobenzonitrile (**8l**) (69 mg, 0.50 mmol), $[Pd_2(dba)_3]$ (4.6 mg, 0.005 mmol), **56** (9.6 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-hexane/EtOAc: 5/1) yielded **26ba** (61 mg, 67%) as an off-white solid.
m.p. 60–62 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.71 (ddd, J = 4.8, 1.7, 1.0 Hz, 1H), 8.31 (m, 1H), 8.23 (m, 1H), 7.80 (m, 1H), 7.76–7.65 (m, 2H), 7.57 (m, 1H), 7.30 (ddd, J = 7.3, 4.8, 1.3, 1H).
^{13}C-NMR (126 MHz, $CDCl_3$) δ = 154.8 (C_q), 149.8 (CH), 140.3 (C_q), 137.0 (CH), 132.1 (CH), 130.9 (CH), 130.5 (CH), 129.4 (CH), 123.0 (CH), 120.4 (CH), 118.6 (C_q), 112.9 (C_q).
IR (KBr): 3070, 2226, 1581, 1408, 1263, 1016, 767 cm^{-1}.
MS (EI) m/z (relative intensity) 180 (100) [M^+], 153 (18), 127 (10), 75 (10), 51 (18).
HR-MS (EI) m/z calcd for $C_{12}H_8N_2$ 180.0687, found 180.0681.
The spectral data were in accordance with those reported in the literature.[110]

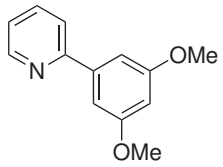
Synthesis of 2-(4-fluorophenyl)pyridine (26bb)



The representative procedure C was followed, using **24a** (205 mg, 0.75 mmol), 1-chloro-4-fluorobenzene (**8f**) (65 mg, 0.50 mmol), $[Pd_2(dba)_3]$ (4.6 mg, 0.005 mmol), **56** (9.6 mg, 0.02 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 20 h, purification by chromatography (*n*-hexane/EtOAc: 10/1 → 5/1) yielded **26bb** (57 mg, 66%) as a colorless solid. m.p. 39–41 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.67 (ddd, J = 4.8, 1.8, 1.0 Hz, 1H), 8.03–7.93 (m, 2H), 7.77–7.62 (m, 2H), 7.24–7.10 (m, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 163.4 ($^1J_{C–F}$ = 247 Hz, C_q), 156.4 (C_q), 149.6 (CH), 136.8 (CH), 135.5 ($^4J_{C–F}$ = 3 Hz, C_q), 128.6 ($^3J_{C–F}$ = 8 Hz, CH), 122.0 (CH), 120.2

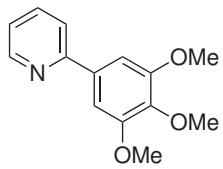
(CH), 115.6 ($^2J_{C–F}$ = 21 Hz, CH).
^{19}F-NMR (282 MHz, $CDCl_3$) δ = –113.2 (m).
IR (KBr): 3749, 2580, 1604, 1513, 1468, 1436, 1226, 1161, 845, 780 cm^{-1}.
MS (EI) m/z (relative intensity) 173 (100) [M^+], 146 (6), 75 (1), 51 (1).
HR-MS (EI) m/z calcd for $C_{11}H_8FN+H^+$ 174.0714, found 174.0713.
The spectral data were in accordance with those reported in the literature.[128]

Synthesis of 2-(3,5-dimethoxyphenyl)pyridine (26bc)



The representative procedure C was followed, using **24a** (205 mg, 0.75 mmol), 1-chloro-3,5-dimethoxybenzene (**8m**) (86 mg, 0.50 mmol), [$Pd_2(dba)_3$] (4.6 mg, 0.005 mmol), **56** (9.6 mg, 0.03 mmol) and K_3PO_4 (318 mg, 1.50 mmol). After 24 h, purification by chromatography (*n*-hexane/EtOAc: 5/1 → 2/1) yielded **26bc** (77 mg, 72%) as a yellow oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.64 (m, 1H), 7.71–7.62 (m, 2H), 7.17 (ddd, J = 6.3, 4.8, 2.3 Hz, 1H), 7.14 (d, J = 2.3 Hz, 2H), 6.50 (dd, J = 2.3, 2.3 Hz, 1H), 3.82 (s, 6H).
^{13}C-NMR (126 MHz, $CDCl_3$) δ = 160.9 (C_q), 156.8 (C_q), 149.2 (CH), 141.3 (C_q), 136.5 (CH), 122.2 (CH), 120.5 (CH), 104.7 (CH), 101.2 (CH), 55.4 (CH_3).
IR (ATR): 3000, 2959, 2837, 1584, 1565, 1454, 1414, 1202, 1148, 778 cm^{-1}.
MS (EI) m/z (relative intensity) 214 (100) [M-H^+], 185 (46), 154 (25), 141 (20), 129 (18), 78 (13), 51 (13).
HR-MS (EI) m/z calcd for $C_{13}H_{13}NO_2$ 215.0946, found 215.0951.
The spectral data were in accordance with those reported in the literature.[129]

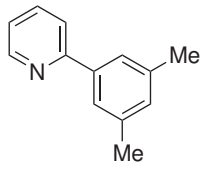
Synthesis of 2-(3,4,5-trimethoxyphenyl)pyridine (26bd)



The representative procedure D was followed, using **43** (5.0 mL, 1.50 mmol, 0.3M in THF), 3,4,5-(trimethoxy)bromobenzene (**2m**) (247 mg, 1.00 mmol), [$Pd_2(dba)_3$] (18.3 mg, 0.02 mmol) and **56** (25.5 mg, 0.08 mmol). After 20 h, purification by chromatography (*n*-hexane/EtOAc: 4/1) yielded **26bd** (161 mg, 66%) as a white solid.
m.p. 52-54 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.65 (m, 1H), 7.72–7.65 (m, 2H), 7.21 (s, 2H), 7.20

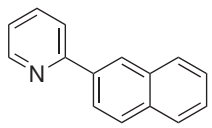
(m, 1H), 3.92 (s, 6H), 3.87 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 156.9 (C_q), 153.4 (C_q), 149.4 (CH), 138.9 (C_q), 136.6 (CH), 135.0 (C_q), 121.9 (CH), 120.2 (CH), 104.0 (CH), 60.9 (CH_3), 56.1 (CH_3)
IR (KBr): 3459, 2935, 2834, 2365, 1589, 1511, 1407, 1348, 1255, 1132, 989, 777 cm^{-1}.
MS (EI) m/z (relative intensity) 245 (100) [M^+], 230 (52), 202 (16), 172 (22), 116 (12), 89 (6), 78 (5), 51 (4).
HR-MS (EI) m/z calcd for $C_{14}H_{15}NO_3$+H^+ 246.1125, found 246.1129.

Synthesis of 2-(3,5-dimethylphenyl)pyridine (26be)



The representative procedure D was followed, using **43** (5.0 mL, 1.50 mmol, 0.3M in THF), 1-bromo-3,5-dimethylbenzene (**2n**) (187 mg, 1.00 mmol), [$Pd_2(dba)_3$] (18.3 mg, 0.02 mmol) and **56** (25.5 mg, 0.08 mmol). After 20 h, purification by chromatography (*n*-hexane/EtOAc: 4/1) yielded **26be** (141 mg, 76%) as a yellow oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.69 (dt, J = 4.8, 1.4 Hz, 1H), 7.77–7.69 (m, 2H), 7.60 (s, 2H), 7.21 (ddd, J = 5.9, 4.9, 2.6 Hz, 1H), 7.07 (s, 1H), 2.40 (s, 6H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 157.7 (C_q), 149.5 (CH), 139.3 (C_q), 138.2 (C_q), 136.6 (CH), 130.6 (CH), 124.7 (CH), 121.9 (CH), 120.6 (CH), 21.4 (CH_3).
IR (ATR): 3005, 2916, 2859, 1700, 1587, 1564, 1444, 1288, 854, 781 cm^{-1}.
MS (EI) m/z (relative intensity) 183 (100) [M^+], 167 (47), 77 (10), 51 (12).
HR-MS (EI) m/z calcd for $C_{13}H_{13}N$ 183.1048, found 183.1056.
The spectral data were in accordance with those reported in the literature.[130]

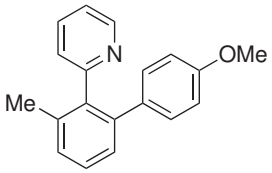
Synthesis of 2-(2-naphthyl)pyridine (26bf)



The representative procedure D was followed, using **43** (5.0 mL, 1.50 mmol, 0.3M in THF), 2-bromonapthalene (**2o**) (207 mg, 1.00 mmol), [$Pd_2(dba)_3$] (18.3 mg, 0.02 mmol) and **56** (25.5 mg, 0.08 mmol). After 20h, purification by chromatography (*n*-hexane/EtOAc: 10/1) yielded **26bf** (190 mg, 93%) as a yellow solid. m.p. 68–70 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.76 (dm, J = 4.4 Hz, 1H), 8.49 (s, 1H), 8.15 (dd, J = 8.6, 1.8 Hz, 1H), 8.00–7.84 (m, 4H), 7.83–7.75 (m, 1H), 7.55–7.47 (m, 2H), 7.26 (ddd, J = 7.4, 4.8, 1.2 Hz, 1H).

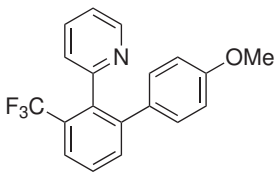
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 157.3 (C_q), 149.7 (CH), 136.8 (CH), 136.6 (C_q), 133.6 (C_q), 133.5 (C_q), 128.7 (CH), 128.4 (CH), 127.6 (CH), 126.5 (CH), 126.3 (CH), 126.3 (CH), 124.5 (CH), 122.1 (CH), 120.8 (CH).
IR (KBr): 3423, 2361, 1591, 1478, 1438, 1422, 1151, 781 cm^{-1}
MS (EI) m/z (relative intensity) 205 (100) [M^+], 176 (12), 151 (8), 102 (10), 43 (5).
HR-MS (EI) m/z calcd for $C_{15}H_{11}N$ 205.0891, found 205.0889.
The spectral data were in accordance with those reported in the literature.[113]

Synthesis of 4′-methoxy-3-methyl-2-(pyridin-2-yl)biphenyl (33aa)



The representative procedure F was followed using 2-*o*-tolylpyridine (**29d**) (85 mg, 0.50 mmol), 4-chloroanisole (**8b**) (109 mg, 0.75 mmol), **66** (14 mg, 0.025 mmol) and K_2CO_3 (137 mg, 1.00 mmol). After 18 h, purification by column chromatography on silica gel (*n*-hexane/EtOAc: 5/1) yielded **33aa** (120 mg, 87%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.63 (ddd, J = 5.0, 1.8, 0.9 Hz, 1H), 7.45 (dt, J = 7.6, 1.9 Hz, 1H), 7.32–7.19 (m, 3H), 7.11 (ddd, J = 8.8, 6.2, 1.1 Hz, 1H), 6.99 (dt, J = 8.8, 2.9 Hz, 2H), 6.88 (td, J = 7.7, 1.0 Hz, 1H), 6.65 (dt, J = 8.8 Hz, 2.9 Hz, 2H), 3.71 (s, 3H), 2.16 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 159.5 (C_q), 158.1 (C_q), 148.4 (CH), 140.8 (C_q), 138.1 (C_q), 136.7 (C_q), 136.2 (C_q), 134.0 (CH), 130.7 (CH), 129.1 (CH), 128.1 (CH), 127.6 (CH), 125.8 (CH), 121.4 (CH), 113.1 (CH), 55.1 (CH_3), 20.5 (CH_3).
IR (KBr): 3001, 2956, 2835, 2539, 2044, 1887, 1515, 1378, 1292, 1110, 1034, 835 cm^{-1}.
MS (EI) m/z (relative intensity) 275 (48) [M^+], 274 (100), 260 (33), 231 (23), 115 (18).
HR-MS (ESI) m/z calcd for $C_{19}H_{17}NO$ 275.1310, found 275.1328.
The spectral data were in accordance with those reported in the literature.[45]

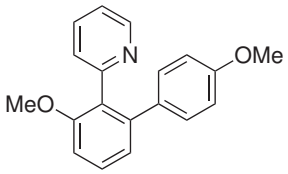
Synthesis of 4′-methoxy-2-(pyridin-2-yl)-3-(trifluoromethyl)biphenyl(33ab)



The representative procedure F was followed using 2-{2-(trifluoromethyl)phenyl}pyridine (**29k**) (120 mg, 0.54 mmol), 4-chloroanisole (**8b**) (107 mg, 0.75 mmol), **66** (14 mg, 0.025 mmol) and K_2CO_3 (137 mg, 1.00 mmol). After 18 h, purification by column chromatog-

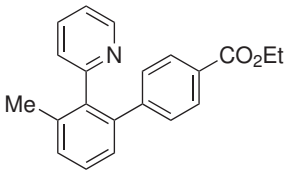
raphy (*n*-hexane/EtOAc: 5/1) yielded **33ab** (168 mg, 94%) as a green solid.
m.p. 78–81 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.57 (ddd, J = 4.9, 1.7, 0.9 Hz, 1H), 7.76 (dd, J = 7.1, 2.1 Hz, 1H), 7.61–7.45 (m, 3H), 7.12 (ddd, J = 7.6, 4.9, 1.2 Hz, 1H), 7.02 (d, J = 7.8 Hz, 1H), 6.97 (d, J = 8.7 Hz, 2H), 6.67 (d, J = 8.7 Hz, 2H), 3.73 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 158.4 (C_q), 156.8 (C_q), 148.4 (CH), 142.9 (C_q), 138.3 (C_q), 135.3 (CH), 133.6 (CH), 132.4 (C_q), 130.7 (CH), 129.2 (C_q, $^2J_{C–F}$ = 30 Hz), 128.2 (CH), 125.6 (CH, $^4J_{C–F}$ = 2 Hz), 124.9 (CH, $^3J_{C–F}$ = 5 Hz), 124.1 (C_q, $^1J_{C–F}$ = 274 Hz), 121.9 (CH), 113.1 (CH), 55.1 (CH_3).
^{19}F-NMR (283 MHz, $CDCl_3$) δ = -57.1 (s).
IR (KBr): 3052, 1610, 1587, 1516, 1426,1326, 1247, 1132, 1046, 812, 743 cm^{-1}.
MS (EI) m/z (relative intensity) 329 (80) [M^+], 314 (100), 308 (24), 285 (14), 265 (10), 237 (8).
HR-MS (ESI) m/z calcd for $C_{19}H_{14}NO_3F$+H^+ 330.1100, found 330.1104.

Synthesis of 3,4′-dimethoxy-2-(pyridin-2-yl)biphenyl (33ac)



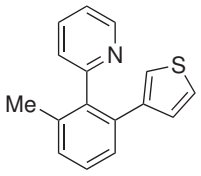
The representative procedure F was followed using 2-(2-methoxyphenyl)pyridine (**29c**) (106 mg, 0.57 mmol), 4-chloroanisole (**8b**) (107 mg, 0.75 mmol), **66** (14 mg, 0.025 mmol) and K_2CO_3 (137 mg, 1.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 1/1) yielded **33ac** (155 mg, 93%) as a dark green solid.
m.p. 111–113 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.58 (ddd, J = 4.9, 1.8, 0.9 Hz, 1H), 7.47 (td, J = 7.7, 1.8 Hz, 1H), 7.40 (dd, J = 8.1, 7.9 Hz, 1H), 7.10–6.92 (m, 6H), 6.67 (d, J = 7.7 Hz, 2H), 3.75 (s, 3H), 3.71 (s, 3H).
^{13}C-NMR (126 MHz, $CDCl_3$) δ = 158.0 (C_q), 157.1 (C_q), 156.9 (C_q), 148.7 (CH), 142.2 (C_q), 135.3 (CH), 133.3 (C_q), 130.5 (CH), 129.0 (CH), 128.9 (C_q), 126.1 (CH), 122.4 (CH), 121.1 (CH), 113.0 (CH), 109.6 (CH), 55.9 (CH_3), 55.1 (CH_3).
IR (KBr): 3050, 2936, 2836, 1609, 1587, 1515, 1464, 1291, 1176, 1025, 835, 740 cm^{-1}.
MS (EI) m/z (relative intensity) 290 (70) [M-H^+], 275 (64), 260 (100), 232 (8), 204 (12), 108 (6).
HR-MS (ESI) m/z calcd for $C_{19}H_{17}NO_2$+Na^+ 314.1151, found 314.1157.

Synthesis of 4-ethoxycarbonyl-3′-methyl-2′-(pyridin-2-yl)biphenyl (33ad)



The representative procedure F was followed using 2-*o*-tolylpyridine (**29d**) (94 mg, 0.56 mmol), 4-chlorobenzoic acid ethylester (**8p**) (158 mg, 0.86 mmol), **66** (14 mg, 0.025 mmol) and K_2CO_3 (137 mg, 1.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 5/1) yielded **33ad** (174 mg, 98%) as a yellow oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.61 (ddd, J = 4.9, 1.8, 1.0 Hz, 1H), 7.81 (d, J = 8.6 Hz, 2H), 7.45 (td, J = 7.7, 1.8 Hz, 1H), 7.37 (dd, J = 7.7, 7.5 Hz, 1H), 7.28–7.23 (m, 2H), 7.14 (d, J = 8.6 Hz, 2H), 7.10 (ddd, J = 7.8, 4.9, 1.2 Hz, 1H), 6.88 (dt, J = 7.8, 1.1 Hz, 1H), 4.32 (q, J = 7.1 Hz, 2H), 2.18 (s, 3H), 1.35 (t, J = 7.1 Hz, 3H).
^{13}C-NMR (126 MHz, $CDCl_3$) δ = 166.4 (C_q), 159.0 (C_q), 148.9 (CH), 146.3 (C_q), 140.2 (C_q), 139.2 (C_q), 136.8 (C_q), 135.7 (CH), 129.9 (CH), 129.5 (CH), 128.8 (CH), 128.2 (C_q), 128.0 (CH), 127.3 (CH), 125.5 (CH), 121.4 (CH), 60.8 (CH_2), 20.5 (CH_3), 14.4 (CH_3).
IR (KBr): 3059, 2979, 1716, 1608, 1563, 1459, 1401, 1274, 1102, 859, 768 cm^{-1}.
MS (EI) m/z (relative intensity) 316 (100) [M-H$^+$], 288 (24), 242 (12), 184 (8), 139 (44), 111 (12), 45 (25).
HR-MS (ESI) m/z calcd for $C_{21}H_{19}NO_2$+H$^+$ 318.1489, found 318.1494.

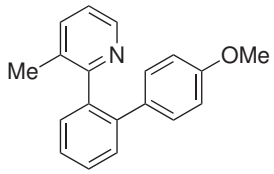
Synthesis of 2-{2-methyl-6-(thiophen-3-yl)phenyl}pyridine (33ae)



The representative procedure F was followed using 2-*o*-tolylpyridine (**29d**) (80 mg, 0.47 mmol), 3-chlorothiophene (**8q**) (104 mg, 0.75 mmol), **66** (14 mg, 0.025 mmol) and K_2CO_3 (137 mg, 1.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 5/1) yielded **33ae** (97 mg, 82%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.67 (ddd, J = 4.9, 1.8, 0.9 Hz, 1H), 7.54 (td, J = 7.7, 1.8 Hz, 1H), 7.35–7.31 (m, 2H), 7.27 (m, 1H), 7.16 (ddd, J = 7.6, 4.9, 1.2 Hz, 1H), 7.05 (dd, J = 5.0, 3.0 Hz, 1H), 6.98 (dt, J = 7.8, 1.0 Hz, 1H), 6.84 (dd, J = 3.0, 1.3 Hz, 1H), 6.70 (dd, J = 5.0, 1.3 Hz, 1H), 2.15 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 159.7 (C_q), 149.0 (CH), 141.9 (C_q), 139.1 (C_q), 136.7 (C_q), 136.0 (CH), 135.7 (C_q), 129.3 (CH), 128.9 (CH), 128.1 (CH), 127.2 (CH), 125.2 (CH), 124.2 (CH), 122.8 (CH), 121.6 (CH), 20.4 (CH_3).

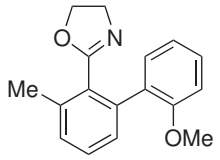
IR (KBr): 3444, 3063, 2363, 1585, 1463, 1422, 1148, 1025, 843, 749, 652 cm^{-1}.
MS (EI) m/z (relative intensity) 250 (100) [M-H^+], 217 (4), 168 (58), 84 (4).
HR-MS (ESI) m/z calcd for $C_{16}H_{13}NS+H^+$ 252.0841, found 252.0840.

Synthesis of 4′-methoxy-2-(3-methylpyridin-2-yl)biphenyl (33af)



The representative procedure F was followed using 3-methyl-2-phenylpyridine (**29l**) (90 mg, 0.53 mmol), 4-chloroanisole (**8b**) (107 mg, 0.75 mmol), **66** (14 mg, 0.025 mmol) and K_2CO_3 (137 mg, 1.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 5/1) yielded **33af** (140 mg, 96%) as a dark green oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.50 (d, J = 3.7 Hz, 1H), 7.49–7.35 (m, 4H), 7.30 (md, J = 7.6 Hz, 1H), 7.09 (dd, J = 7.7, 4.8 Hz, 1H), 7.04 (d, J = 8.8 Hz, 2H), 6.70 (d, J = 8.8 Hz, 2H), 3.74 (s, 3H), 1.74 (s, 3H).
^{13}C-NMR (126 MHz, $CDCl_3$) δ = 159.5 (C_q), 158.2 (C_q), 146.4 (CH), 140.1 (C_q), 139.2 (C_q), 137.3 (CH), 133.4 (C_q), 131.5 (C_q), 130.2 (CH), 129.7 (CH), 129.4 (CH), 128.2 (CH), 126.9 (CH), 121.9 (CH), 113.2 (CH), 55.1 (CH_3), 18.9 (CH_3).
IR (KBr): 3056, 2957, 2835, 1609, 1516, 1291, 1248, 1179, 1037, 834, 763 cm^{-1}.
MS (EI) m/z (relative intensity) 275 (40) [M^+], 260 (60), 217 (6), 84 (100), 47 (86).
HR-MS (ESI) m/z calcd for $C_{19}H_{17}NO+H^+$ 276.1383, found 276.1386.
The spectral data were in accordance with those reported in the literature.[131]

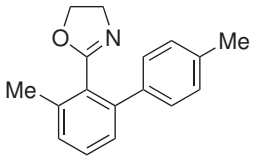
Synthesis of 2-(4,5-dihydrooxazol-2-yl)-2′-methoxy-3-methylbiphenyl (33ag)



The representative procedure F was followed using 2-*o*-tolyl-4,5-dihydrooxazole (**29e**) (101 mg, 0.63 mmol), 2-chloroanisole (**8j**) (124 mg, 0.87 mmol), **66** (14 mg, 0.025 mmol) and K_2CO_3 (137 mg, 1.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 1/1) yielded **33ag** (89 mg, 53%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.33 (dd, J = 7.7, 7.5 Hz,1H), 7.27 (m, 1H), 7.24–7.16 (m, 3H), 6.99–6.89 (m, 2H), 4.05 (t, J = 9.5 Hz, 2H), 3.78 (t, J = 9.5 Hz, 2H), 3.74 (s, 3H), 2.43 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 164.5 (C_q), 156.4 (C_q), 138.7 (C_q), 137.1 (C_q), 130.7

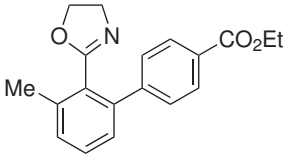
(CH), 130.1 (C_q), 129.0 (CH), 129.0 (CH), 128.9 (C_q), 128.5 (CH), 128.1 (CH), 120.1 (CH), 110.6 (CH), 66.9 (CH_2), 55.5 (CH_3), 55.0 (CH_2), 20.1 (CH_3).
IR (KBr): 3382, 2366, 1657, 1599, 1497, 1468, 1341, 1173, 1036, 936, 763 cm^{-1}.
MS (EI) m/z (relative intensity) 236 (100), 192 (16), 165 (10), 152 (6).
HR-MS (ESI) m/z calcd for $C_{17}H_{17}NO_2$+H^+ 268.1332, found 268.1335.
The spectral data were in accordance with those reported in the literature.[44]

Synthesis of 2-(4,5-dihydrooxazol-2-yl)-3,4′-dimethylbiphenyl (33ah)



The representative procedure F was followed using 2-*o*-tolyl-4,5-dihydrooxazole (**8n**) (99 mg, 0.61 mmol), 4-chlorotoluene (**8n**) (98 mg, 0.77 mmol), **66** (14 mg, 0.025 mmol) and K_2CO_3 (137 mg, 1.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 1/1) yielded **33ah** (136 mg, 89%) as a brown oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.35 (dd, J = 7.9, 7.5 Hz, 1H), 7.32 (d, J = 8.2 Hz, 2H), 7.24–7.15 (m, 4H), 4.15 (t, J = 9.5 Hz, 2H), 3.88 (t, J = 9.5 Hz, 2H), 2.42 (s, 3H), 2.38 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 164.5 (C_q), 141.9 (C_q), 138.2 (C_q), 137.4 (C_q), 136.7 (C_q), 129.4 (CH), 128.7 (CH), 128.7 (CH), 128.2 (CH), 128.0 (C_q), 127.2 (CH), 67.1 (CH_2), 55.1 (CH_2), 21.1 (CH_3), 19.8 (CH_3).
IR (KBr): 3401, 2973, 2359, 1667, 1461, 1346, 1251, 1190, 1112, 1043, 938, 786 cm^{-1}.
MS (EI) m/z (relative intensity) 250 (100) [M-H^+], 206 (10), 178 (6), 165 (8).
HR-MS (ESI) m/z calcd for $C_{17}H_{17}NO$+H^+ 252.1383, found 252.1387.
The spectral data were in accordance with those reported in the literature.[45]

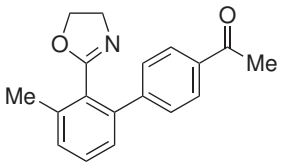
Synthesis of 2′-(4,5-dihydrooxazol-2-yl)-4-ethoxycarbonyl-3′-methylbiphenyl (33ai)



The representative procedure F was followed using 2-*o*-tolyl-4,5-dihydrooxazole (**29e**) (84 mg, 0.52 mmol), 4-chlorobenzoic acid ethylester (**8p**) (148 mg, 0.80 mmol), **66** (14 mg, 0.025 mmol) and K_2CO_3 (137 mg, 1.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 1/1) yielded **33ai** (136 mg, 94%) as a colorless oil.

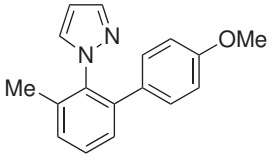
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.05 (d, J = 8.6 Hz, 2H), 7.47 (d, J = 8.6 Hz, 2H), 7.37 (dd, J = 7.8, 7.6 Hz, 1H), 7.29–7.17 (m, 2H), 4.39 (q, J = 7.1 Hz, 2H), 4.13 (t, J = 9.5 Hz, 2H), 3.85 (t, J = 9.5 Hz, 2H), 2.42 (s, 3H), 1.40 (t, J = 7.1 Hz, 3H).
^{13}C NMR (75 MHz, $CDCl_3$) δ = 166.5 (C_q), 164.1 (C_q), 145.8 (C_q), 140.9 (C_q), 137.7 (C_q), 129.6 (CH), 129.6 (CH), 129.2 (CH), 129.1 (C_q), 128.4 (CH), 128.0 (C_q), 127.0 (CH), 67.2 (CH_2), 60.9 (CH_2), 55.1 (CH_2), 19.8 (CH_3), 14.3 (CH_3).
IR (KBr): 3413, 2980, 2481, 1714, 1662, 1463, 1367, 1270, 1181, 1044, 938, 796 cm^{-1}.
MS (EI) m/z (relative intensity) 308 (100) [M-H$^+$], 280 (18), 264 (4), 236 (10), 84 (6).
HR-MS (ESI) m/z calcd for $C_{19}H_{19}NO_3$+H$^+$ 310.1438, found 310.1445.
The spectral data were in accordance with those reported in the literature.[45]

Synthesis of 4-acetyl-3′-methyl-2′-(4,5-dihydrooxazol-2-yl)biphenyl (33aj)



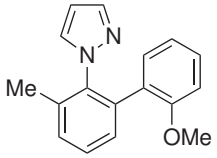
The representative procedure F was followed using 2-*o*-tolyl-4,5-dihydrooxazole (**29e**) (94 mg, 0.58 mmol), 4-chloroacetophenone (**8e**) (117 mg, 0.76 mmol), **66** (14 mg, 0.025 mmol) and K_2CO_3 (137 mg, 1.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 1/1) yielded **33aj** (148 mg, 91%) as a pale green solid. m.p. 84–85 ℃.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.97 (d, J = 8.5 Hz, 2H), 7.50 (d, J = 8.5 Hz, 2H), 7.38 (dd, J = 7.8, 7.6 Hz, 1H), 7.26 (d, J = 7.8 Hz, 1H), 7.21 (d, J = 7.8 Hz, 1H), 4.15 (t, J = 9.5 Hz, 2H), 3.86 (t, J = 9.5 Hz, 2H), 2.63 (s, 3H), 2.42 (s, 3H).
^{13}C NMR (75 MHz, $CDCl_3$) δ = 197.8 (C_q), 164.1 (C_q), 146.1 (C_q), 140.8 (C_q), 137.8 (C_q), 135.7 (C_q), 129.7 (CH), 129.6 (CH), 128.6 (CH), 128.1 (CH), 128.0 (C_q), 127.0 (CH), 67.2 (CH_2), 55.1 (CH_2), 26.6 (CH_3), 19.8 (CH_3).
IR (KBr): 3289, 2342, 1667, 1604, 1460, 1403, 1357, 1113, 1038, 931, 843, 797 cm^{-1}.
MS (EI) m/z (relative intensity) 278 (22) [M-H$^+$], 250 (100), 206 (8), 165 (6).
HR-MS (ESI) m/z calcd for $C_{18}H_{17}NO$+H$^+$ 280.1332, found 280.1336.
The spectral data were in accordance with those reported in the literature.[44]

Synthesis of 4′-methoxy-3-methyl-2-(1*H*-pyrazol-1-yl)biphenyl (33ak)



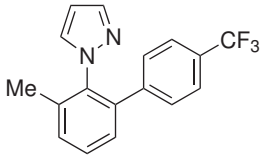
The representative procedure F was followed using 1-*o*-tolyl-1*H*-pyrazole (**29h**) (79 mg, 0.46 mmol), 4-chloroanisole (**8b**) (107 mg, 0.75 mmol), **66** (14 mg, 0.025 mmol) and K_2CO_3 (137 mg, 1.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 5/1) yielded **33ak** (130 mg, 98%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.65 (dd, J = 1.8, 0.5 Hz, 1H), 7.38 (m, 1H), 7.30–7.25 (m, 2H), 7.09 (dd, J = 2.3, 0.6 Hz, 1H), 7.00 (d, J = 8.9 Hz, 2H), 6.74 (d, J = 8.9 Hz, 2H), 6.20 (t, J = 2.1 Hz, 1H), 3.75 (s, 3H), 2.11 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 158.7 (C_q), 139.6 (CH), 139.4 (C_q), 137.7 (C_q), 136.9 (C_q), 131.4 (CH), 131.0 (C_q), 129.5 (CH), 129.3 (CH), 128.9 (CH), 128.0 (CH), 113.4 (CH), 105.9 (CH), 55.0 (CH_3), 17.6 (CH_3).
IR (KBr): 2957, 2836, 1610, 1515, 1469, 1442, 1405, 1391, 1317, 1294, 1251, 1181, 1099, 1034, 939, 870, 835, 788, 756, 625 cm^{-1}.
MS (EI) m/z (relative intensity) 264 (79) [M^+], 263 (100), 249, (5), 236 (6), 220 (4), 152 (4), 84 (12).
HR-MS (ESI) m/z calcd for $C_{17}H_{17}N_2O$ 265.1335, found 265.1334.
The spectral data were in accordance with those reported in the literature.[45]

Synthesis of 2′-methoxy-3-methyl-2-(1*H*-pyrazol-1-yl)biphenyl (33al)



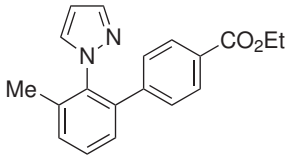
The representative procedure F was followed using 1-*o*-tolyl-1*H*-pyrazole (**29h**) (73 mg, 0.46 mmol), 2-chloroanisole (**8j**) (120 mg, 0.84 mmol), **66** (14 mg, 0.025 mmol) and K_2CO_3 (137 mg, 1.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 5/1) yielded **33al** (97 mg, 80%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.53 (dd, J = 1.8, 0.6 Hz, 1H), 7.38 (m, 1H), 7.31 (m, 1H), 7.27–7.22 (m, 1H), 7.20 (dd, J = 1.8, 0.8 Hz, 1H), 7.17 (m, 1H), 7.01 (dd, J = 7.5, 1.6 Hz, 1H), 6.84–6.77 (m, 2H), 6.10 (dd, J = 2.3, 1.9 Hz, 1H), 3.66 (s, 3H), 2.15 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 156.3 (C_q), 139.2 (CH), 138.7 (C_q), 136.6 (C_q), 136.1 (C_q), 131.0 (CH), 130.7 (CH), 130.0 (CH), 128.8 (CH), 128.7 (CH), 128.2 (CH), 127.6 (C_q), 120.0 (CH), 110.2 (CH), 104.9 (CH), 55.2 (CH_3), 17.9 (CH_3).
IR (KBr): 3056, 2960, 2836, 1601, 1498, 1470, 1239, 1025, 938, 752 cm^{-1}.
MS (EI) m/z (relative intensity) 264 (2) [M^+], 233 (100), 181 (6), 152 (2).
HR-MS (ESI) m/z calcd for $C_{17}H_{16}N_2O$+H^+ 265.1335, found 265.1337.

Synthesis of 3-methyl-2-(1*H*-pyrazol-1-yl)-4′-(trifluoromethyl)biphenyl (33am)



The representative procedure F was followed using 1-*o*-tolyl-1*H*-pyrazole (**29h**) (89 mg, 0.56 mmol), 4-chlorobenzotrifluoride (**8k**) (150 mg, 0.83 mmol), **66** (14 mg, 0.025 mmol) and K_2CO_3 (137 mg, 1.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 5/1) yielded **33am** (167 mg, 99%) as a colorless solid.
m.p. 70–71 °C.
^{1}H NMR (300 MHz, $CDCl_3$) δ = 7.65 (d, J = 1.9 Hz, 1H), 7.47 (d, J = 8.0 Hz, 2H), 7.44 (dd, J = 7.5, 7.5 Hz, 1H), 7.37 (m, 1H), 7.31 (dd, J = 7.4, 1.8 Hz, 1H), 7.20 (d, J = 8.0 Hz, 2H), 7.10 (d, J = 2.4 Hz, 1H), 6.22 (t, J = 2.0 Hz, 1H), 2.14 (s, 3H).
^{13}C NMR (75 MHz, $CDCl_3$) δ = 142.3 (C_q), 139.9 (CH), 138.5 (C_q), 137.8 (C_q), 137.2 (C_q), 131.4 (CH), 130.8 (CH), 129.2 (C_q, $^2J_{C–F}$ = 33 Hz), 129.2 (CH), 128.5 (CH), 128.0 (CH), 124.9 (CH, $^3J_{C–F}$ = 4 Hz), 124.1 (C_q, $^1J_{C–F}$ = 272 Hz), 106.3 (CH), 17.6 (CH_3).
^{19}F-NMR (283 MHz, $CDCl_3$) δ = -62.5 (s).
IR (KBr): 3053, 2984, 1618, 1519, 1473, 1403, 1326, 1265, 1126, 939, 738 cm^{-1}.
MS (EI) m/z (relative intensity) 301 (100) [M-H$^+$], 274 (14), 204 (4), 165 (6).
HR-MS (ESI) m/z calcd for $C_{17}H_{13}N_2F_3$+H$^+$ 303.1104, found 303.1108.

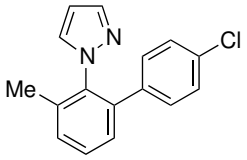
Synthesis of 4-ethoxycarbonyl-3′-methyl-2′-(1*H*-pyrazol-1-yl)biphenyl (33an)



The representative procedure F was followed using 1-*o*-tolyl-1*H*-pyrazole (**29h**) (80 mg, 0.51 mmol), 4-chlorobenzoic acid ethylester (**8p**) (148 mg, 0.80 mmol), **66** (14 mg, 0.025 mmol) and K_2CO_3 (138 mg, 1.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 5/1) yielded **33an** (152 mg, 97%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.88 (d, J = 8.6 Hz, 2H), 7.63 (d, J = 1.8 Hz, 1H), 7.42 (dd, J = 7.5, 7.5 Hz, 1H), 7.33 (m, 2H), 7.15 (d, J = 8.6 Hz, 2H), 7.07 (d, J = 2.3 Hz, 1H), 6.19 (t, J = 2.3 Hz, 1H), 4.34 (q, J = 7.1 Hz, 2H), 2.13 (s, 3H), 1.36 (t, J = 7.1 Hz, 3H).
^{13}C NMR (126 MHz, $CDCl_3$) δ = 166.2 (C_q), 143.2 (C_q), 139.7 (CH), 138.8 (C_q), 137.7 (C_q), 137.0 (C_q), 131.3 (CH), 130.6 (CH), 129.2 (CH), 129.1 (C_q), 129.0 (CH), 128.1 (CH), 127.9 (CH), 106.1 (CH), 60.9 (CH_2), 17.7 (CH_3), 14.4 (CH_3).
IR (KBr): 2981, 2929, 1716, 1610, 1518, 1474, 1367, 1274, 1182, 1044, 939, 794 cm^{-1}.

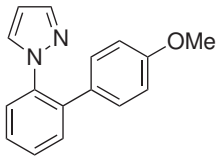
MS (EI) m/z (relative intensity) 305 (100) [M-H$^+$], 277 (18), 263 (16), 233 (8), 204 (8), 165 (4).
HR-MS (ESI) m/z calcd for $C_{19}H_{18}N_2O_2$+H$^+$ 307.1441, found 307.1445.
The spectral data were in accordance with those reported in the literature.[45]

Synthesis of 4′-chloro-3-methyl-2-(1*H*-pyrazol-1-yl)biphenyl (33ao)



The representative procedure F was followed using 1-*o*-tolyl-1*H*-pyrazole (**29h**) (82 mg, 0.52 mmol), 1-bromo-4-chlorobenzene (**2v**) (144 mg, 0.75 mmol), **66** (14 mg, 0.025 mmol) and K_2CO_3 (138 mg, 1.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 10/1) yielded **33ao** (138 mg, 98%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.65 (d, J = 1.4 Hz, 1H), 7.41 (dd, J = 7.6, 7.6 Hz, 1H), 7.36–7.25 (m, 2H), 7.18 (d, J = 8.6 Hz, 2H), 7.10 (d, J = 2.3 Hz, 1H), 7.02 (d, J = 8.6 Hz, 2H), 6.22 (t, J = 2.1 Hz, 1H), 2.12 (s, 3H).
^{13}C NMR (126 MHz, $CDCl_3$) δ = 139.8 (CH), 138.7 (C_q), 137.7 (C_q), 137.1 (C_q), 137.1 (C_q), 133.3 (C_q), 131.4 (CH), 130.3 (CH), 129.5 (CH), 129.1 (CH), 128.2 (CH), 127.9 (CH), 106.2 (CH), 17.6 (CH_3).
IR (ATR): 3120, 3051, 2961, 2923, 1514, 1495, 1396, 1187, 1012, 937, 744 cm^{-1}.
MS (EI) m/z (relative intensity) 267 (100) [M-H$^+$], 240 (22), 204 (26), 165 (25), 152 (10), 139 (8), 43 (24).
HR-MS (ESI) m/z calcd for $C_{16}H_{13}ClN_2$+H$^+$ 269.0840, found 269.0846.

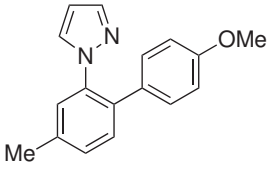
Synthesis of 4′-methoxy-2-(1*H*-pyrazol-1-yl)biphenyl (33ap)



The representative procedure F was followed using 1-phenyl-1*H*-pyrazole (**29p**) (292 mg, 2.03 mmol), 4-chloroanisole (**8b**) (143 mg, 1.00 mmol), **66** (28 mg, 0.05 mmol, 5.0 mol %) and K_2CO_3 (276 mg, 2.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 10/1) yielded **33ap** (244 mg, 97%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.64 (dd, J = 1.8, 0.5 Hz, 1H), 7.59 (m, 1H), 7.47–7.40 (m, 3H), 7.11 (dd, J = 2.4, 0.6, 1H), 7.02 (d, J = 8.9 Hz, 2H), 6.82 (d, J = 8.9 Hz, 2H), 6.21 (dd, J = 2.2, 2.2 Hz, 1H), 3.79 (s, 3H).

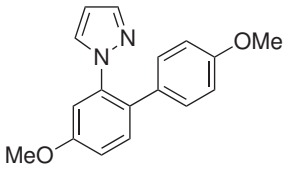
^{13}C NMR (126 MHz, $CDCl_3$) δ = 158.9 (C_q), 140.1 (CH), 138.5 (C_q), 136.3 (C_q), 131.2 (CH), 130.9 (CH), 130.8 (C_q), 129.6 (CH), 128.2 (CH), 127.9 (CH), 126.6 (CH), 113.8 (CH), 106.3 (CH), 55.1 (CH_3).
IR (KBr): 3001, 2957, 2836, 2360, 1610, 1516, 1459, 1250, 1102, 1201, 760 cm^{-1}.
MS (EI) m/z (relative intensity) 249 (100) [M-H$^+$], 234 (4), 206 (8), 139 (6).
HR-MS (ESI) m/z calcd for $C_{16}H_{14}N_2O$+H$^+$ 251.1179, found 251.1180.

Synthesis of 4′-methoxy-4-methyl-2-(1*H*-pyrazol-1-yl)biphenyl (33aq)



The representative procedure F was followed using 1-*m*-tolyl-1*H*-pyrazole (**29i**) (316 mg, 2.00 mmol), 4-chloroanisole (**8b**) (143 mg, 1.00 mmol), **66** (28 mg, 0.05 mmol, 5.0 mol %) and K_2CO_3 (276 mg, 2.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 10/1) yielded **33aq** (259 mg, 98%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.64 (d, J = 1.8 Hz, 1H), 7.42 (s, 1H), 7.33 (d, J = 7.8 Hz, 1H), 7.24 (m, 1H), 7.08 (dd, J = 2.4, 0.5 Hz, 1H), 7.00 (d, J = 8.9 Hz, 2H), 6.80 (d, J = 8.9 Hz, 2H), 6.19 (dd, J = 2.3, 2.0 Hz, 1H), 3.78 (s, 3H), 2.43 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 158.8 (C_q), 140.0 (CH), 138.1 (C_q), 138.0 (C_q), 133.3 (C_q), 131.2 (CH), 130.8 (C_q), 130.7 (CH), 129.6 (CH), 128.9 (CH), 127.0 (CH), 113.8 (CH), 106.2 (CH), 55.1 (CH_3), 20.8 (CH_3).
IR (KBr): 3030, 2961, 1610, 1493, 1401, 1252, 1107, 1042, 953, 739 cm^{-1}.
MS (EI) m/z (relative intensity) 263 (100) [M-H$^+$], 248 (4), 220 (6), 205 (4), 152 (2).
HR-MS (ESI) m/z calcd for $C_{17}H_{16}N_2O$+H$^+$ 265.1335, found 265.1334.

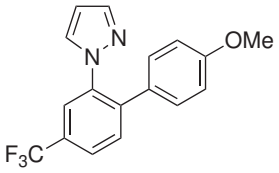
Synthesis of 4,4′-dimethoxy-2-(1*H*-pyrazol-1-yl)biphenyl (33ar)



The representative procedure F was followed using 1-(3-methoxyphenyl)-1*H*-pyrazole (**29j**) (352 mg, 2.02 mmol), 4-chloroanisole (**8b**) (143 mg, 1.00 mmol), **66** (28 mg, 0.05 mmol, 5.0 mol %) and K_2CO_3 (276 mg, 2.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 10/1) yielded **33ar** (268 mg, 96%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.64 (d, J = 1.8 Hz, 1H), 7.34 (d, J = 8.6 Hz, 1H), 7.14 (d, J = 2.7 Hz, 1H), 7.08 (d, J = 2.4 Hz, 1H), 6.98 (m, 1H), 6.95 (d, J = 8.7 Hz,

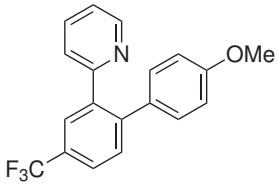
2H), 6.80 (d, J = 8.7 Hz, 2H), 6.19 (dd, J = 2.4, 1.9 Hz, 1H), 3.87 (s, 3H), 3.79 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 159.2 (C_q), 158.7 (C_q), 140.2 (CH), 139.1 (C_q), 131.7 (CH), 131.3 (CH), 130.7 (C_q), 129.6 (CH), 128.5 (C_q), 114.9 (CH), 113.8 (CH), 111.0 (CH), 106.3 (CH), 55.6 (CH_3), 55.2 (CH_3).
IR (KBr): 3024, 2958, 2836, 2360, 1611, 1493, 1401, 1250, 1179, 1047, 951, 754 cm^{-1}.
MS (EI) m/z (relative intensity) 279 (100) [M-H$^+$], 264 (8), 249 (4), 221 (6).
HR-MS (ESI) m/z calcd for $C_{17}H_{16}N_2O_2$+Na^+ 303.1104, found 303.1107.

Synthesis of 4-trifluoromethyl-4′-methoxy-2-(1*H*-pyrazol-1-yl)biphenyl (33as)



The representative procedure F was followed using 1-{3-(trifluoromethyl)phenyl}-1*H*-pyrazole (**29o**) (357 mg, 2.00 mmol), 4-chloroanisole (**8b**) (145 mg, 1.02 mmol), **66** (28 mg, 0.05 mmol, 5.0 mol %) and K_2CO_3 (276 mg, 2.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 20/1) yielded **33as** (274 mg, 86%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.90 (s, 1H), 7.68–7.64 (m, 2H), 7.55 (d, J = 8.1 Hz, 1H), 7.09 (d, J = 2.3 Hz, 1H), 7.02 (d, J = 8.8 Hz, 2H), 6.84 (d, J = 8.8 Hz, 2H), 6.25–6.21 (m, 1H), 3.79 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 159.6 (C_q), 140.8 (CH), 139.5 (C_q), 138.7 (C_q), 131.6 (CH), 131.2 (CH), 130.2 (C_q, $^2J_{C–F}$ = 33 Hz), 129.6 (CH), 129.4 (C_q), 124.6 (CH, $^3J_{C–F}$ = 4 Hz), 123.7 (CH, $^3J_{C–F}$ = 4Hz), 123.6 (C_q, $^1J_{C–F}$ = 272 Hz), 114.1 (CH), 107.0 (CH), 55.2 (CH_3).
^{19}F-NMR (283 MHz, $CDCl_3$) δ = -62.6 (s).
IR (KBr): 2960, 2838, 1607, 1517, 1457, 1338, 1245, 1123, 1035, 825 cm^{-1}.
MS (EI) m/z (relative intensity) 317 (100) [M-H$^+$], 274 (10), 139 (6), 84 (6).
HR-MS (EI) m/z calcd for $C_{17}H_{12}N_2OF_3$+H^+ 319.1053, found 319.1063.

Synthesis of 4′-methoxy-4-trifluoromethyl-2-(pyridin-2-yl)biphenyl (33at)



The representative procedure F was followed using 2-{3′-(trifluoromethyl)phenyl}pyridine (**29p**) (238 mg, 1.07 mmol), 4-chloroanisole (**8b**) (91 mg, 0.64 mmol), **66** (14 mg, 0.025 mmol, 5.0 mol %) and K_2CO_3 (138 mg, 2.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 20/1 → 10/1) yielded **33at** (191 mg, 91%) as a pale yellow solid. m.p. 78–80 °C.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.67 (dd, J = 4.9, 0.8 Hz, 1H), 7.96 (d, J = 0.7, 1H), 7.68 (d, J = 8.1 Hz, 1H), 7.52 (d, J = 8.1 Hz, 1H), 7.43 (m, 1H), 7.15 (m, 1H), 7.08 (d, J = 8.7 Hz, 2H), 6.90 (dd, J = 7.9, 0.8 Hz, 1H), 6.79 (d, J = 8.7 Hz, 2H), 3.79 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$) δ = 159.1 (C_q), 158.0 (C_q), 149.7 (CH), 143.6 (C_q), 139.8 (C_q), 135.5 (CH), 132.2 (C_q), 130.9 (CH), 130.7 (CH), 129.5 (C_q, $^2J_{C–F}$ = 33 Hz), 127.5 (CH, $^3J_{C–F}$ = 4 Hz), 125.3 (CH), 125.1 (CH, $^3J_{C–F}$ = 4 Hz), 124.1 (C_q, $^1J_{C–F}$ = 272 Hz), 121.9 (CH), 113.8 (CH), 55.2 (CH_3).

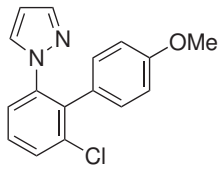
^{19}F-NMR (283 MHz, $CDCl_3$) δ = –62.4 (s).

IR (ATR): 3056, 2840, 1605, 1516, 1465, 1335, 1111, 787 cm^{-1}.

MS (EI) m/z (relative intensity) 328 (100) [M-H$^+$], 314 (14), 285 (22).

HR-MS (EI) m/z calcd for $C_{19}H_3NOF_3$+H$^+$ 330.1100, found 330.1101.

Synthesis of 6-chloro-4′-methoxy-2-(1*H*-pyrazol-1-yl)biphenyl (33au)



The representative procedure F was followed using 1-(3-chlorophenyl)-1*H*-pyrazole (**29n**) (357 mg, 2.00 mmol), 4-bromoanisole (**2c**) (198 mg, 1.06 mmol), **66** (28 mg, 0.05 mmol, 5.0 mol %) and K_2CO_3 (276 mg, 2.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 30/1) yielded **33au** (125 mg, 96%) as a colorless solid. m.p. 81–83 °C.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.65–7.62 (m, 2H), 7.42–7.33 (m, 2H), 7.06 (dd, J = 2.4, 0.5, 1H), 6.99 (d, J = 8.9 Hz, 2H), 6.82 (d, J = 8.9 Hz, 2H), 6.21 (dd, J = 2.4, 1.9 Hz, 1H), 3.80 (s, 3H).

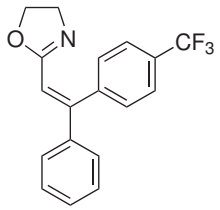
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 159.2 (C_q), 140.6 (CH), 139.1 (C_q), 134.5 (C_q), 133.4 (C_q), 131.9 (CH), 131.2 (CH), 129.7 (C_q), 129.6 (CH), 128.2 (CH), 126. 6 (CH), 114.0 (CH), 106.7 (CH), 55.2 (CH_3).

IR (ATR): 3106, 2956, 2836, 1609, 1596, 1561, 1516, 1401, 1243, 999, 762 cm^{-1}.

MS (EI) m/z (relative intensity) 283 (100) [M-H$^+$], 268 (4), 240 (4), 205 (4) 124 (3).

HR-MS (ESI) m/z calcd for $C_{16}H_{13}N_2OCl$ 285.0789, found 285.0797.

Synthesis of (*Z*)-2-[2-{4-(trifluoromethyl)phenyl}-2-phenylvinyl]-4,5-dihydrooxazole (33av)



The representative procedure F was followed using (*E*)-2-styryl-4,5-dihydrooxazole (**29m**) (87 mg, 0.50 mmol), 4-bromobenzotrifluoride (**2p**) (189 mg, 0.75 mmol), **66** (14 mg, 0.025 mmol, 5.0 mol %) and K_2CO_3 (138 mg, 1.00 mmol). After 18 h, purification by column chromatography on silica gel (*n*-hexane/EtOAc: 1/1) yielded **33av** as a yellow solid (92 mg, 58%). m.p. 123–126 ℃.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.59 (d, J = 8.0 Hz, 2H), 7.39–7.26 (m, 5H), 7.25–7.19 (m, 2H), 6.57 (s, 1H), 4.05 (t, J = 9.3 Hz, 2H), 3.83 (t, J = 9.3 Hz, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$) δ = 163.7 (C_q), 150.4 (C_q), 143.0 (C_q), 143.0 (C_q), 129.9 (CH), 129.8 (C_q, $^2J_{C–F}$ = 32 Hz), 129.0 (CH), 128.4 (CH), 128.0 (CH), 124.5 (CH, $^3J_{C–F}$ = 4 Hz), 124.1 (C_q, $^1J_{C–F}$ = 272 Hz), 115.4 (CH), 67.4 (CH_2), 54.4 (CH_2).

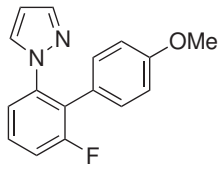
^{19}F-NMR (283 MHz, $CDCl_3$) δ = –62.5 (s).

IR (NaCl): 3053, 2976, 2880, 1645, 1367, 1265, 1125, 990 cm^{-1}.

MS (EI) m/z (relative intensity) 316 (100) [M-H$^+$], 272 (6), 252 (4), 189 (2).

HR-MS (ESI) m/z calcd for C18H14F3NO+Na$^+$ 340.0920, found 340.0921.

Synthesis of 6-fluoro-4′-methoxy-2-(1*H*-pyrazol-1-yl)biphenyl (33aw) and 1-(4,4"-dimethoxy-6′-fluoro-[1,1′:3′,1"]-terphenyl-2′-yl-1*H*-pyrazole (33ax)

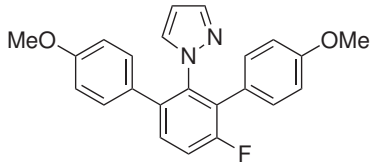


The representative procedure F was followed using 1-(3-fluorophenyl)-1*H*-pyrazole (**29b**) (162 mg, 1.00 mmol), 4-chloroanisole (**8b**) (71 mg, 0.50 mmol), **66** (14 mg, 0.025 mmol, 5.0 mol %) and K_2CO_3 (138 mg, 1.00 mmol). After 18h, purification by column chromatography (*n*-hexane/EtOAc: 10/1) yielded **33aw** (69 mg, 51%) as a colorless oil and **33ax** (22 mg, 24%) as colorless oil.

^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.60 (dd, J = 1.8, 0.5 Hz, 1H), 7.48–7.36 (m, 2H), 7.18 (ddd, J = 9.5, 8.0, 1.6 Hz, 1H), 7.06 (m, 2H), 7.02 (dd, J = 2.5, 0.6 Hz, 1H), 6.85 (d, J = 9.1 Hz, 2H), 6.16 (dd, J = 2.4, 1.9 Hz, 1H), 3.80 (s, 3H).

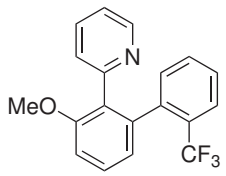
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 160.0 (C_q, $^1J_{C–F}$ = 247 Hz), 159.3 (C_q), 140.3 (CH),

140.2 (C_q), 131.2 (CH), 130.9 (CH), 128.7 (CH, $^3J_{C–F}$ = 8 Hz), 124.4 (C_q, $^2J_{C–F}$ = 18 Hz), 123.5 (C_q), 121.8 (CH, $^4J_{C–F}$ = 3 Hz), 115.1 (CH, $^2J_{C–F}$ = 23 Hz), 113.9 (CH), 106.5 (CH), 55.1 (CH_3).
^{19}F-NMR (283 MHz, $CDCl_3$) δ = –113.6 (m).
IR (KBr): 3052, 2963, 2838, 2359, 1609, 1517, 1400, 1248, 1179, 1032, 878, 738 cm^{-1}.
MS (EI) m/z (relative intensity) 267 (100) [M-H$^+$], 252 (6), 224 (10), 157 (4), 84 (10).
HR-MS (ESI) m/z calcd for $C_{16}H_{13}FN_2O$+H$^+$ 269.1085, found 269.1100.



^{1}H-NMR (300 MHz, $CDCl_3$) δ = 7.44–7.23 (m, 3H), 7.08–7.00 (m, 3H), 6.96 (d, J = 8.8 Hz, 2H), 6.77 (d, J = 8.7 Hz, 2H), 6.74 (d, J = 8.8 Hz, 2H), 6.03 (dd, J = 2.4, 1.9 Hz, 1H), 3.75 (s, 3H), 3.75 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 159.0 (C_q, $^1J_{C–F}$ = 247 Hz), 159.0 (C_q), 158.8 (C_q), 139.5 (CH), 137.9 (C_q, $^4J_{C–F}$ = 4 Hz), 136.0 (C_q, $^3J_{C–F}$ = 4 Hz), 132.2 (CH), 130.5 (CH, $^4J_{C–F}$ = 2 Hz), 130.4 (C_q), 130.1 (CH, $^3J_{C–F}$ = 9 Hz), 129.3 (CH), 128.2 (C_q, $^2J_{C–F}$ = 17 Hz), 123.8 (C_q), 116.4 (CH, $^2J_{C–F}$ = 23 Hz), 113.6 (CH), 113.4 (CH), 106.1 (CH), 55.1(CH_3), 55.1 (CH_3).
IR (NaCl): 2924, 2853, 1608, 1458, 1284, 1067, 814 cm^{-1}.
MS (EI) m/z (relative intensity) 373 (100) [M-H$^+$], 329 (5), 241 (4), 187 (4).
HR-MS (ESI) m/z calcd for $C_{23}H_{19}FN_2O_2$+Na$^+$ 397.1323, found 397.1324.

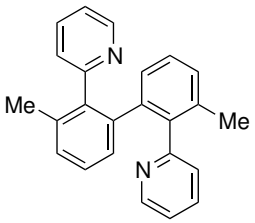
Synthesis of 3-methoxy-2-(pyridin-2-yl)-2′-(trifluoromethyl)biphenyl (33ay)



The representative procedure F was followed using 2-(2-methoxyphenyl)pyridine (**29c**) (104 mg, 0.56 mmol), 2-chlorobenzotrifluoride (**8o**) (135 mg, 0.75 mmol), **66** (14 mg, 0.025 mmol, 5.0 mol %) and K_2CO_3 (138 mg, 1.00 mmol). After 18 h, purification by column chromatography on silica gel (*n*-hexane/EtOAc: 5/1 → 1/1) yielded **33ay** as a brown solid (137 mg, 74%). m.p. 143–145 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.50 (ddd, J = 4.8, 1.7, 0.9 Hz, 1H), 7.56 (m, 1H), 7.40 (ddd, J =10.9, 8.0, 4.8 Hz, 2H), 7.27–7.18 (m, 2H), 7.11 (m, 1H), 7.06–6.92 (m, 4H), 3.78 (s, 3H).

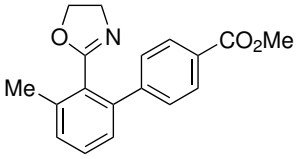
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 156.8 (C_q), 156.1 (C_q), 148.4 (CH), 139.8 (C_q), 139.1 (C_q, $^3J_{C–F}$ = 2 Hz), 135.3 (CH), 133.1 (CH), 130.1 (CH), 129.3 (C_q), 128.7 , 128.3 (C_q, $^2J_{C–F}$ = 30 Hz), 128.0 (CH), 126.7 (CH), 125.5 (CH, $^3J_{C–F}$ = 5 Hz), 125.3 (CH), 124.0 (C_q, $^1J_{C–F}$ = 272 Hz), 122.3 (CH, $^4J_{C–F}$ = 2Hz), 121.2 (CH), 110.5 (CH), 55.8 (CH_3).
^{19}F-NMR (283 MHz, $CDCl_3$) δ = –57.2 (s).
IR (NaCl): 2965, 2841, 1589, 1571, 1465, 1435, 1313, 1253, 1117, 990, 802 cm^{-1}.
MS (EI) m/z (relative intensity) 329 (14) [M^+], 260 (100), 245 (18), 217 (16), 187 (18), 109 (6).
HR-MS (ESI) m/z calcd for $C_{19}H_{14}F_3NO$ 330.1100, found 330.1105.

Synthesis of 2,2′-(pyridin-2-yl)-3,3′-dimethylbiphenyl (33az)



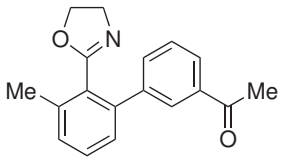
The representative procedure F was followed using 2-(*o*-tolyl)pyridine (**29d**) (98 mg, 0.58 mmol), 2-chlorobenzotrifluoride (**8o**) (135 mg, 0.75 mmol), **66** (14 mg, 0.025 mmol, 5.0 mol %) and K_2CO_3 (138 mg, 1.00 mmol). After 18 h, purification by column chromatography on silica gel (*n*-hexane/EtOAc: 3/1 → 1/1) yielded **33az** as a colorless solid (62 mg, 63%). m.p. 154–155 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.55 (d, J = 4.7 Hz, 2H), 7.52 (td, J = 7.7, 1.6 Hz, 2H), 7.30 (d, J = 7.6 Hz, 2H), 7.08–6.99 (m, 4H), 6.92 (dd, J = 7.6, 7.6 Hz, 2H), 6.76 (d, J = 7.6 Hz, 2H), 2.09 (s, 6H).
^{13}C-NMR (75 MHz, $CDCl_3$) δ = 159.4 (C_q), 148.6 (CH), 140.1 (C_q), 139.7 (C_q), 135.8 (C_q), 135.3 (CH), 128.7 (CH), 128.4 (CH), 126.5 (CH), 125.5 (CH), 121.0 (CH), 20.6 (CH_3).
IR (NaCl): 3042, 2919, 2855, 1715, 1583, 1561, 1452, 1422, 1091, 747 cm^{-1}.
MS (EI) m/z (relative intensity) 336 (77) [M^+], 335 (100), 258 (23), 168 (17).
HR-MS (ESI) m/z calcd for $C_{24}H_{20}N_2$+H^+ 337.1699, found 337.1699.

Synthesis of 2′-(4,5-dihydrooxazol-2-yl)-3′-methylbiphenyl-4-carboxylic acid methylester (33ba)



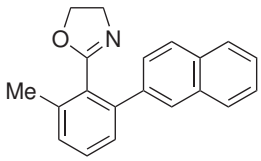
The representative procedure F was followed using 2-*o*-tolyl-4,5-dihydrooxazole (**29e**) (170 mg, 1.05 mmol), 4-methoxycarbonylphenyl tosylate (**30g**) (367 mg, 1.20 mmol), **66** (28 mg, 0.05 mmol) and K_2CO_3 (276 mg, 2.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 10/1 → 3/1 → 1/1) yielded **33ba** (179 mg, 58%) as a brown solid. m.p. 117–118 °C. Lit.:[46] 115–116 °C.
^{1}H-NMR (300 MHz, $CDCl_3$) δ = 8.04 (d, J = 8.2 Hz, 2H), 7.47 (d, J = 8.2 Hz, 2H), 7.37 (dd, J = 7.6, 7.6 Hz, 1H), 7.28–7.18 (m, 2H), 4.13 (t, J = 9.5 Hz, 2H), 3.93 (s, 3H), 3.85 (t, J = 9.5 Hz, 2H), 2.42 (s, 3H).
^{13}C NMR (126 MHz, $CDCl_3$) δ = 167.0 (C_q), 164.0 (C_q), 146.0 (C_q), 140.9 (C_q), 137.8 (C_q), 129.6 (CH), 129.6 (CH), 129.3 (CH), 128.8 (C_q), 128.4 (CH), 128.1 (C_q), 127.0 (CH), 67.2 (CH_2), 55.1 (CH_2), 52.1 (CH_3), 19.8 (CH_3).
IR (ATR): 2950, 2882, 1724, 1664, 1609, 1434, 1194, 1039, 930, 768 cm^{-1}.
MS (EI) m/z (relative intensity) 294 (100) [M-H$^+$], 250 (14), 191 (8), 165 (12).
HR-MS (EI) m/z calcd for $C_{18}H_{17}NO_3$ 295.1208, found 295.1203.
The spectral data were in accordance with those reported in the literature.[46]

Synthesis of 3-methylcarbonyl-{2′-(4,5-dihydrooxazol-2-yl)-3′-methyl} biphenyl (33bb)



The representative procedure F was followed using 2-*o*-tolyl-4,5-dihydrooxazole (**29e**) (166 mg, 1.03 mmol), 3-acetylphenyl tosylate (**30b**) (348 mg, 1.20 mmol), **66** (28 mg, 0.05 mmol) and K_2CO_3 (276 mg, 2.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 3/1 → 1/1) yielded **33bb** (246 mg, 86%) as a brown oil.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.03 (dd, J = 1.7, 1.4 Hz, 1H), 7.92 (md, J = 7.9 Hz, 1H), 7.62 (md, J = 7.7 Hz, 1H), 7.47 (dd, J = 7.7, 7.7 Hz, 1H), 7.38 (dd, J = 7.6, 7.6 Hz, 1H), 7.27–7.22 (m, 2H), 4.16 (t, J = 9.6 Hz, 2H), 3.84 (t, J = 9.6 Hz, 2H), 2.60 (s, 3H), 2.42 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 197.9 (C_q), 164.2 (C_q), 141.5 (C_q), 140.8 (C_q), 137.7 (C_q), 136.9 (C_q), 133.0 (CH), 129.6 (CH), 129.4 (CH), 128.6 (CH), 128.3 (CH), 128.2 (C_q), 127.1 (CH), 126.9 (CH), 67.2 (CH_2), 55.2 (CH_2), 26.6 (CH_3), 19.8 (CH_3).
IR (KBr): 2965, 2881, 1665, 1597, 1456, 1358, 1233, 1038, 968, 932, 787 cm^{-1}.
MS (EI) m/z (relative intensity) 278 (100) [M-H$^+$], 251 (6), 236 (15), 165 (14), 43 (11).
HR-MS (ESI) m/z calcd for $C_{18}H_{17}NO_2$ 279.1259, found 279.1262.
The spectral data were in accordance with those reported in the literature.[46]

Synthesis of 2-{2-methyl-6-(naphthalen-2-yl)phenyl}-4,5-dihydrooxazole (33bc)



The representative procedure F was followed using 2-*o*-tolyl-4,5-dihydrooxazole (**29e**) (166 mg, 1.03 mmol), 2-naphthyltosylate (**30d**) (358 mg, 1.20 mmol), **66** (28 mg, 0.05 mmol) and K_2CO_3 (276 mg, 2.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 3/1 → 1/1) yielded **33bc** (266 mg, 90%) as a brown solid. m.p. 151–153 ℃.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.92 (s, 1H), 7.88-7.84 (m, 3H), 7.59 (m, 1H), 7.49 (m, 1H), 7.48 (d, J = 9.6 Hz, 1H), 7.46–7.31 (m, 2H), 7.27 (d, J = 6.8 Hz, 1H), 4.10 (t, J = 9.4 Hz, 2H), 3.84 (t, J = 9.4 Hz, 2H), 2.47 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 164.4 (C_q), 141.9 (C_q), 138.7 (C_q), 137.6 (C_q), 133.2 (C_q), 132.4 (C_q), 129.5 (CH), 129.0 (CH), 128.3 (C_q), 128.1 (CH), 127.5 (CH), 127.5 (CH), 127.4 (CH), 127.2 (CH), 126.8 (CH), 126.0 (CH), 125.8 (CH), 67.2 (CH_2), 55.1 (CH_2), 19.8 (CH_3).

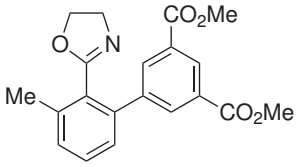
IR (KBr): 3056, 2894, 1662, 1475, 1455, 1251, 1235, 1072, 933 cm^{-1}.

MS (EI) m/z (relative intensity) 286 (100) [M-H$^+$], 278 (11), 242 (10), 215 (12), 43 (7).

HR-MS (ESI) m/z calcd for $C_{20}H_{17}NO$ 287.1310, found 287.1313.

The spectral data were in accordance with those reported in the literature.[46]

Synthesis of 2′-(4,5-dihydrooxazol-2-yl)-3′-methylbiphenyl-3,5-dicarboxylic acid dimethylester (33bd)



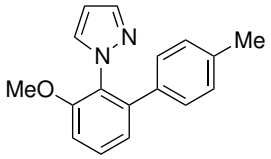
The representative procedure G was followed using 2-*o*-tolyl-4,5-dihydrooxazole (**29e**) (162 mg, 1.00 mmol), dimethyl 5-hydroxyisophthalate **1c** (252 mg, 1.20 mmol), **66** (28 mg, 0.05 mmol), *p*-TsCl (229 mg, 1.20 mmol) and K_2CO_3 (276 mg, 2.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 3/1 → 1/1) yielded **33bd** (272 mg, 77%) as a brown solid. m.p. 140–142 ℃.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 8.64 (dd, J = 1.6, 1.6 Hz, 1H), 8.32 (d, J = 1.6 Hz, 2H), 7.44–7.36 (dd, J = 7.8, 7.5 Hz, 1H), 7.27 (d, J = 7.8 Hz, 2H), 4.21 (t, J = 9.5 Hz, 2H), 3.94 (s, 6H), 3.84 (t, J = 9.5 Hz, 2H), 2.43 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 166.1 (C_q), 164.0 (C_q), 141.7 (C_q), 139.6 (C_q), 137.9

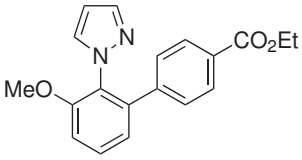
(C_q), 133.7 (CH), 130.5 (C_q), 129.8 (CH), 129.8 (CH), 129.4 (CH), 128.2 (C_q), 127.0 (CH), 67.2 (CH_2), 55.2 (CH_2), 52.3 (CH_3), 19.8 (CH_3).
IR (KBr): 2955, 1718, 1661, 1433, 1343, 1248, 1045, 1000, 935 cm^{-1}.
MS (EI) m/z (relative intensity) 352 (100) [M-H^+], 338 (10), 320 (12), 294 (20), 279 (15), 250 (7), 165 (8).
HR-MS (ESI) m/z calcd for $C_{20}H_{19}NO_5$ 353.1263, found 353.1263.

Synthesis of 4-methyl (3′-methoxy-2′-(1*H*-pyrazol-1-yl)biphenyl (33be)



The representative procedure G was followed using 1-(2-methoxyphenyl)-1*H*-pyrazole (**29f**) (168 mg, 0.96 mmol), **67** (177 mg, 0.60 mmol), **66** (28 mg, 0.05 mmol) and K_2CO_3 (276 mg, 2.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 1/1) yielded **33be** (168 mg, 66%) as a colorless solid. m.p. 95–97 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.65 (m, 1H), 7.43 (m, 1H), 7.23 (d, J = 2.3, 1H), 7.09 (md, J = 7.9 Hz, 1H), 7.05–6.97 (m, 5H), 6.25 (dd, J = 2.3, 2.1 Hz, 1H), 3.82 (s, 3H), 2.30 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 155.7 (C_q), 141.2 (C_q), 139.7 (CH), 137.0 (C_q), 135.3 (C_q), 132.2 (CH), 129.8 (CH), 128.8 (CH), 128.0 (CH), 127.7 (C_q), 122.4 (CH), 110.7 (CH), 105.7 (CH), 56.2 (CH_3), 21.1 (CH_3).
IR (ATR): 3136, 3014, 2836, 1584, 1517, 1472, 1262, 1110, 1013, 746 cm^{-1}.
MS (EI) m/z (relative intensity) 263 (100) [M-H^+], 248 (46), 233 (16), 220 (12), 115 (6).
HR-MS (ESI) m/z calcd for $C_{17}H_{16}N_2O$ 264.1263, found 264.1266.

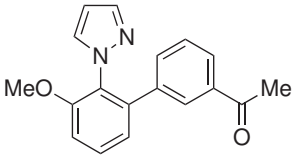
Synthesis of 3′-methoxy-2′-(1*H*-pyrazol-1-yl)biphenyl-4-carboxylic acid ethylester (33bf)



The representative procedure G was followed using 1-(2-methoxyphenyl)-1*H*-pyrazole (**29f**) (172 mg, 0.99 mmol), 4-hydroxybenzoic acid ethylester (**1d**) (199 mg, 1.20 mmol), **66** (28 mg, 0.05 mmol), *p*-TsCl (229 mg, 1.20 mmol) and K_2CO_3 (276 mg, 2.00 mmol). After 18 h, purification by column chromatography (*n*-pentane/EtOAc: 5/1 → 3/1) yielded **33bf** (217 mg, 68%) as a colorless solid. m.p. 115–116 °C.

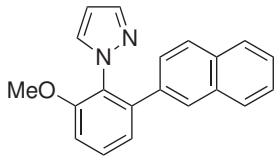
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.92–7.86 (d, J = 8.4 Hz, 2H), 7.60 (d, J = 1.8 Hz, 1H), 7.48 (dd, J = 8.1, 8.1 Hz, 1H), 7.24 (d, J = 2.3 Hz, 1H), 7.15 (d, J = 8.4 Hz, 2H), 7.08 (dd, J = 8.1, 2.6 Hz, 2H), 6.24 (dd, J = 2.3, 2.1 Hz, 1H), 4.34 (q, J = 7.1 Hz, 2H), 3.83 (s, 3H), 1.37 (t, J = 7.1 Hz, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 166.4 (C_q), 155.7 (C_q), 142.9 (C_q), 140.2 (C_q), 139.9 (CH), 132.2 (CH), 129.9 (CH), 129.2 (CH), 128.1 (CH), 127.7 (C_q), 122.2 (CH), 111.6 (CH), 106.0 (CH), 60.9 (CH_2), 56.3 (CH_3), 14.3 (CH_3).
IR (KBr): 2987, 2844, 1708, 1512, 1468, 1439, 1276, 1086, 1016, 738 cm^{-1}.
MS (EI) m/z (relative intensity) 321 (100) [M-H$^+$], 293 (33), 278 (23), 249 (10), 205 (12), 149 (13), 59 (22), 43 (37).
HR-MS (ESI) m/z calcd for $C_{19}H_{18}N_2O_3$+H$^+$ 323.1390, found 323.1385.

Synthesis of 3-methylcarbonyl (3′-methoxy-2′-(1*H*-pyrazol-1-yl)biphenyl (33bg)



The representative procedure G was followed using 1-(2-methoxyphenyl)-1*H*-pyrazole (**29f**) (163 mg, 0.94 mmol), 1-(3-hydroxyphenyl)ethanone (**1e**) (163 mg, 1.20 mmol), **66** (28 mg, 0.05 mmol), *p*-TsCl (229 mg, 1.20 mmol) and K_2CO_3 (276 mg, 2.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 5/1 → 3/1 → 1/1) yielded **33bg** (218 mg, 79%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.86–7.79 (m, 1H), 7.66 (dd, J = 2.6, 1.5 Hz, 1H), 7.61 (d, J = 1.9 Hz, 1H), 7.49 (dd, J = 8.1, 8.1 Hz, 1H), 7.32 (m, 2H), 7.25 (dd, J = 2.4, 0.6 Hz, 1H), 7.11 (dd, J = 7.8, 1.2 Hz, 1H), 7.07 (dd, J = 8.4, 1.2 Hz, 1H), 6.23 (dd, J = 2.3, 2.1 Hz, 1H), 3.83 (s, 3H), 2.48 (s, 3H).
^{13}C-NMR (125 MHz, $CDCl_3$): δ = 197.8 (C_q), 155.7 (C_q), 140.0 (C_q), 139.8 (CH), 138.5 (C_q), 136.8 (C_q), 132.7 (CH), 132.2 (CH), 130.0 (CH), 128.4 (CH), 128.3 (CH), 127.6 (C_q), 126.9 (CH), 122.1 (CH), 111.4 (CH), 106.0 (CH), 56.2 (CH_3), 26.5 (CH_3).
IR (KBr): 3116, 2970, 1680, 1575, 1518, 1480, 1354, 1265, 1242, 1087, 915, 756 cm^{-1}.
MS (EI) m/z (relative intensity) 292 (100) [M$^+$], 276 (22), 261 (15), 249 (20), 234 (15), 205 (17), 43 (22).
HR-MS (ESI) m/z calcd for $C_{18}H_{16}N_2O_2$ 292.1212, found 292.1212.
The spectral data were in accordance with those reported in the literature.[46]

Synthesis of 1-{2-methoxy-6-(naphthalen-2-yl)phenyl}-1*H*-pyrazole (33bh)



The representative procedure G was followed using 1-(2-methoxyphenyl)-1*H*-pyrazole (**29f**) (190 mg, 1.09 mmol), 2-naphthol (**1f**) (173 mg, 1.20 mmol), **66** (28 mg, 0.05 mmol), *p*-TsCl (229 mg, 1.20 mmol) and K_2CO_3 (276 mg, 2.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 5/1 → 3/1) yielded **33bh** (273 mg, 83%) as a colorless oil.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.75 (dd, J = 8.9, 4.3 Hz, 2H), 7.68–7.62 (m, 3H), 7.52–7.40 (m, 3H), 7.26–7.03 (m, 4H), 6.18 (dt, J = 2.3, 1.8 Hz, 1H), 3.83 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 155.7 (C_q), 141.0 (C_q), 139.8 (CH), 135.8 (C_q), 133.1 (C_q), 132.3 (C_q), 132.3 (CH), 129.8 (CH), 128.1 (CH), 127.9 (C_q), 127.4 (CH), 127.4 (CH), 127.3 (CH), 126.1 (CH), 126.0 (CH), 125.9 (CH), 122.6 (CH), 111.0 (CH), 105.8 (CH), 56.2 (CH_3).

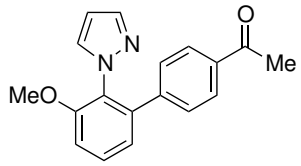
IR (KBr): 3052, 2936, 2838, 1581, 1518, 1475, 1305, 1266, 1104, 1030, 739 cm^{-1}.

MS (EI) m/z (relative intensity) 299 (100) [M-H$^+$], 284 (40), 269 (18), 256 (15), 189 (8), 128 (7).

HR-MS (ESI) m/z calcd for $C_{20}H_{16}N_2O$ 300.1263, found 300.1260.

The spectral data were in accordance with those reported in the literature.[46]

Synthesis of 4-methylcarbonyl (3′-methoxy-2′-(1*H*-pyrazol-1-yl)biphenyl (33bi)



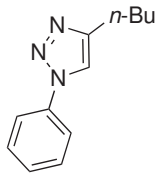
The representative procedure G was followed using 1-(2-methoxyphenyl)-1*H*-pyrazole (**29f**) (180 mg, 1.03 mmol), 4-hydroxyphenyl ethanone (**1f**) (163 mg, 1.20 mmol), **66** (28 mg, 0.05 mmol), mesitylcarboxylic acid **65** (30mg, 0.30 mmol), *p*-TsCl (229 mg, 1.20 mmol) and K_2CO_3 (276 mg, 2.00 mmol). After 18 h, purification by column chromatography (*n*-hexane/EtOAc: 2/1 → 1/1) yielded **33bi** (226 mg, 75%) as a grey solid. m.p. 116–118 °C. Lit.:[46] 116–117 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.80 (d, J = 8.6 Hz, 2H), 7.60 (dd, J = 1.9, 0.6 Hz, 1H), 7.48 (dd, J = 8.1, 8.1 Hz, 1H), 7.26 (m, 1H), 7.18 (d, J = 8.6 Hz, 2H), 7.10–7.05 (m, 2H), 6.24 (dd, J = 1.9, 1.9 Hz, 1H), 3.83 (s, 3H), 2.55 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 197.7 (C_q), 155.6 (C_q), 143.2 (C_q), 140.0 (C_q), 139.9

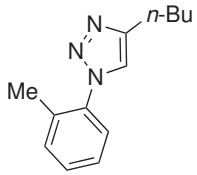
(CH), 135.7 (C_q), 132.3 (CH), 130.0 (CH), 128.4 (CH), 128.1 (CH), 127.7 (C_q), 122.1 (CH), 111.6 (CH), 106.1 (CH), 56.3 (CH_3), 26.6 (CH_3).
IR (KBr): 3137, 3026, 2974, 2937, 1672, 1584, 1471, 1268, 1011, 751 cm^{-1}.
MS (EI) m/z (relative intensity) 291 (100) [M-H^+], 276 (34), 261 (18), 249 (13), 205 (15), 178 (5), 43 (14).
HR-MS (EI) m/z calcd for $C_{18}H_{16}N_2O_2$ 292.1212, found 292.1213.
The spectral data were in accordance with those reported in the literature.[46]

Synthesis of 4-*n*-butyl-1-phenyl-1*H*-1,2,3 triazole (37c)



To a degassed solution of DMSO/H_2O (150 mL, 5/1), NaN_3 (3.42 g, 52.5 mmol), iodobenzene (10.2 g, 50.0 mmol), 1-hexyne (4.13 g, 50.0 mmol), CuI (953 mg, 5.00 mmol, 10 mol %), sodium ascorbate (991 mg, 5.00 mmol, 10 mol %) and DMEDA (669 mg, 7.50 mmol, 15 mol %) were added sequentially. The mixture was stirred overnight at ambient temperature. H_2O (100 mL) and MTBE (100 mL) were added to the reaction mixture. The separated aqueous phase was extracted with MTBE (2 × 100 mL). The combined organic layers were washed with H_2O (100 mL) and *sat. aq.* NH_3 until the disappearance of the blue color, as well as with brine (100 mL), dried over Na_2SO_4 and concentrated *in vacuo*. The remaining residue was purified by column chromatography on silica gel (*n*-hexane/EtOAc: 5/1) to yield 4-*n*-butyl-1-phenyl-1*H*-1,2,3-triazole (**37c**) (10.0 g, 99%) as a colorless oil. m.p. 38–40 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.71–7.68 (m, 1H), 7.67–7.61 (m, 2H), 7.44–7.36 (m, 2H), 7.34–7.26 (m, 1H), 2.76–2.67 (m, 2H), 1.70–1.58 (m, 2H), 1.35 (m, 2H), 0.87 (td, *J* = 7.3, 1.7, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 148.9 (C_q), 137.0 (C_q), 129.4 (CH), 128.1 (CH), 120.1 (CH), 118.6 (CH), 31.3 (CH_2), 25.1 (CH_2), 22.1 (CH_2), 13.6 (CH_3).
IR (KBr): 3121, 2961, 2929, 1594, 1551, 1498, 1465, 1243, 1039, 757 cm^{-1}.
MS (EI) *m/z* (relative intensity) 201 (2) [M^+], 172 (10), 158 (12), 130 (100), 77 (70), 51 (20), 43 (18).
HR-MS (ESI) *m/z* calcd for $C_{12}H_{15}N_3$ 201.1266, found 201.1271.

Synthesis of 4-*n*-butyl-1-(*o*-tolyl)-1*H*-1,2,3-triazole (37d)



To a degassed solution of DMSO/H_2O (150 mL, 5/1), NaN_3 (3.42 g, 52.5 mmol), 2-iodotoluene (10.9 g, 50.0 mmol), 1-hexyne (4.14 g, 50.0 mmol), CuI (952 mg, 5.00 mmol, 10 mol %), sodium ascorbate (995 mg, 5.00 mmol, 10 mol %) and DMEDA (659 mg, 7.50 mmol, 15 mol %) were added sequentially. The reaction mixture was stirred overnight at ambient temperature. H_2O (100 mL) and MTBE (100 mL) were added to the reaction mixture. The separated aqueous phase was extracted with MTBE (2 × 100 mL). The combined organic layers were washed with H_2O (100 mL) and several times with aqueous ammonia until the disappearance of the blue colour, then with brine (100 mL), dried over Na_2SO_4 and concentrated *in vacuo*. The remaining residue was purified by column chromatography on silica gel (*n*-hexane/EtOAc: 5/1) to yield 4-*n*-butyl-1-(*o*-tolyl)-1*H*-1,2,3-triazole (**37d**) (9.46 g, 88%) as a colorless oil.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.41 (s, 1H), 7.34–7.22 (m, 4H), 2.74 (t, J = 7.7 Hz, 2H), 2.13 (s, 3H), 1.66 (quint, J = 7.2 Hz, 2H), 1.36 (sext, J = 7.2 Hz, 2H), 0.89 (t, J = 7.3 Hz, 3H).

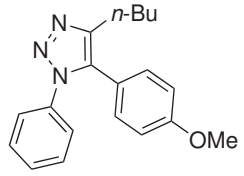
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 148.0 (C_q), 136.6 (C_q), 133.5 (C_q), 131.2 (CH), 129.4 (CH), 126.6 (CH), 125.8 (CH), 122.1 (CH), 31.4 (CH_2), 25.2 (CH_2), 22.2 (CH_2), 17.7 (CH_3), 13.7 (CH_3).

IR (KBr): 2956, 2929, 2860, 1501, 1463, 1381, 1213, 1038, 987, 760 cm^{-1}.

MS (EI) *m/z* (relative intensity) 186 (8), 144 (100), 131 (10), 91 (50), 65 (18), 43 (15).

HR-MS (ESI) *m/z* calcd for $C_{13}H_{17}N_3$ 216.1495, found 216.1500.

Synthesis of 4-*n*-butyl-5-(4-methoxyphenyl)-1-phenyl-1*H*-1,2,3 triazole (40a)

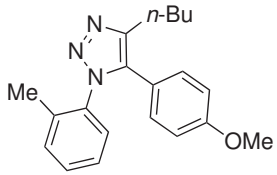


The representative procedure H was followed, using 4-*n*-butyl-1-phenyl-1*H*-1,2,3 triazole (**37c**) (170 mg, 0.845 mmol), 4-iodoanisole (**77a**) (598 mg, 2.53 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). After 19 h, purification by chromatography (*n*-hexane/ethyl acetate 7/1 → 5/1 → 4/1) yielded **40a** (185 mg, 71%) as a light-red solid. m.p. 95–96 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.37–7.26 (m, 5H), 7.07 (dt, J = 9.3, 2.5 Hz, 2H),

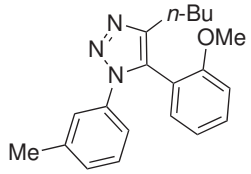
6.89 (dt, J = 9.3, 2.5 Hz, 2H), 3.82 (s, 3H), 2.75–2.69 (m, 2H), 1.76–1.66 (m, 2H), 1.36 (tq, J = 7.5, 7.5 Hz, 2H), 0.89 (t, J = 7.3 Hz, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 159.8 (C_q), 146.0 (C_q), 136.9 (C_q), 133.6 (C_q), 130.8 (CH), 129.0 (CH), 128.5 (CH), 124.8 (CH), 119.7 (C_q), 114.2 (CH), 55.2 (CH_3), 31.8 (CH_2), 24.8 (CH_2), 22.5 (CH_2), 13.8 (CH_3).
IR (KBr): 3853, 3744, 3054, 2987, 2361, 1653, 1559, 1540, 1506, 1420 cm^{-1}.
MS (EI) m/z (relative intensity) 307 (10) [M$^+$], 279 (47), 236 (65), 133 (100), 77 (11).
HR-MS (ESI) m/z calcd for $C_{19}H_{22}N_3O$ 308.1757, found 308.1758.

Synthesis of 4-*n*-butyl-5-(4-methoxyphenyl)-1-(*o*-tolyl)-1*H*-1,2,3-triazole (40b)



The representative procedure H was followed, using 4-*n*-butyl-1-(*o*-tolyl)-1*H*-1,2,3 triazole (**37d**) (225 mg, 1.03 mmol), 4-iodoanisole (**77a**) (709 mg, 3.00 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). After 14 h, purification by chromatography (*n*-hexane/EtOAc: 9/1) yielded **40b** (225 mg, 70%) (as two diastereomers) as an off-white solid. m.p. 86–88 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.26 (m, 1H), 7.20–7.14 (m, 3H), 7.01–6.95 (m, 2H), 6.80–6.74 (m, 2H), 3.71(I)/3.70 (II) (s, 3H), 2.78–2.69 (m, 2H), 1.90 (s, 3H), 1.71 (m, 2H), 1.35 (m, 2H), 0.86(I)/0.86(II) (t, J = 7.3 Hz, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 159.6 (C_q), 144.7 (C_q), 136.0 (C_q), 135.0 (C_q), 134.7 (C_q), 130.9 (CH), 130.2 (CH), 129.5 (CH), 127.6 (CH), 126.4 (CH), 119.3 (C_q), 114.0, 55.0 (CH_3), 31.6 (CH_2), 24.9 (CH_2), 22.4 (CH_2), 17.4 (CH_3), 13.7 (CH_3).
IR (ATR): 2953, 2930, 1611, 1505, 1442, 1291, 1253, 1020, 840, 768 cm^{-1}.
MS (EI) m/z (relative intensity) 321 (6) [M$^+$], 293 (24), 250 (30), 205 (18), 133 (40), 107 (100), 91 (8), 43 (6).
HR-MS (ESI) m/z calcd for $C_{20}H_{23}N_3O$ 322.1841, found 322.1837.

Synthesis of 4-*n*-butyl-5-(2-methoxyphenyl)-1-(*m*-tolyl)-1*H*-1,2,3-triazole (40c)



The representative procedure H was followed, using 4-*n*-butyl-1-(*m*-tolyl)-1*H*-1,2,3 triazole (**37e**) (215 mg, 1.00 mmol), 2-iodoanisole (**77b**) (702 mg, 3.00 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). After 20 h, purification by chromatography (*n*-hexane/EtOAc: 12/1 → 10/1 → 9/1) yielded **40c** (295 mg, 92%) as an off-white solid. m.p. 92–94 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.35 (ddd, J = 8.3, 7.4, 1.8 Hz, 1H), 7.18 (s, 1H), 7.16–7.06 (m, 3H), 7.00–6.91 (m, 2H), 6.82 (dd, J = 8.4, 0.8 Hz, 1H), 3.43 (s, 3H), 2.63 (t, J = 7.6 Hz, 2H), 2.27 (s, 3H), 1.65 (m, 2H), 1.30 (tq, J = 7.5, 7.5 Hz, 2H), 0.83 (t, J = 7.3 Hz, 3H).

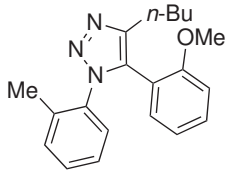
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 157.3 (C_q), 147.1 (C_q), 139.1 (C_q), 137.9 (C_q), 131.6 (CH), 131.2 (CH), 131.1 (C_q), 129.2 (CH), 128.7 (CH), 124.7 (CH), 121.0 (CH), 120.8 (CH), 117.2 (C_q), 111.5 (CH), 55.2 (CH_3), 31.8 (CH_2), 25.1 (CH_2), 22.6 (CH_2), 21.5 (CH_3), 14.0 (CH_3).

IR (KBr): 2955, 2859, 1737, 1613, 1507, 1293, 1252, 1178, 1035, 834, 695, 612 cm^{-1}.

MS (EI) *m/z* (relative intensity) 321 (6) [M$^+$], 293 (37), 250 (50), 133 (100), 91 (15), 77 (4), 65(10).

HR-MS (ESI) *m/z* calcd for $C_{20}H_{24}N_3O$ 322.1914, found 322.1914.

Synthesis of 4-*n*-butyl-5-(2-methoxyphenyl)-1-(*o*-tolyl)-1*H*-1,2,3-triazole (40d)



The representative procedure H was followed, using 4-*n*-butyl-1-(*o*-tolyl)-1*H*-1,2,3 triazole (**37d**) (215 mg, 1.00 mmol), 2-iodoanisole (**77b**) (703 mg, 3.00 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). After 20 h, purification by chromatography (*n*-hexane/EtOAc: 9/1) yielded **40d** (243 mg, 76%) as a yellow oil.

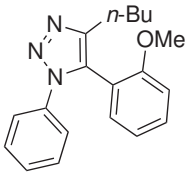
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.34–7.18 (m, 3H), 7.14–7.04 (m, 3H), 6.91 (td, J = 7.5, 1.0 Hz, 1H), 6.78 (d, J = 8.4 Hz, 1H), 3.51 (s, 3H), 2.70–2.62 (t, J = 7.6 Hz, 2H), 2.07 (s, 3H), 1.69 (m, 2H), 1.33 (tq, J = 7.5, 7.5 Hz, 2H), 0.86 (t, J = 7.3 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 156.9 (C_q), 146.0 (C_q), 136.4 (C_q), 135.0 (C_q), 132.2 (C_q), 131.4 (CH), 130.8 (CH), 130.7 (CH), 129.1 (CH), 126.9 (CH), 125.8 (CH), 120.4 (CH), 116.4 (C_q), 110.9 (CH), 54.8 (CH_3), 31.4 (CH_2), 24.9 (CH_2), 22.4 (CH_2), 17.6 (CH_3), 13.8 (CH_3).

IR (ATR): 2955, 2930, 2859, 1686, 1584, 1488, 1245, 1023, 995, 796 cm^{-1}.

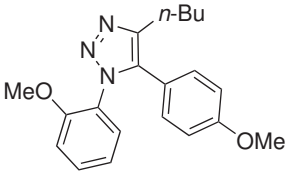
MS (EI) *m/z* (relative intensity) 321 (4) [M^+], 293 (60), 250 (100), 133 (20), 105 (30), 91 (16), 65 (8).
HR-MS (EI) *m/z* calcd for $C_{20}H_{23}N_3O+H^+$ 322.1914, found 322.1913.

Synthesis of 4-*n*-butyl-5-(2-methoxyphenyl)-1-phenyl-1*H*-1,2,3-triazole (40e)



The representative procedure H was followed, using 4-*n*-butyl-1-phenyl-1*H*-1,2,3 triazole (**37c**) (203 mg, 1.00 mmol), 2-iodoanisole (**77b**) (702 mg, 3.00 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). After 20 h, purification by column chromatography (*n*-hexane/EtOAc: 9/1 → 7/1) yielded **40e** (247 mg, 80%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.36 (m, 1H), 7.31–7.24 (m, 4H), 7.15 (dd, J = 5.7, 1.7 Hz, 1H), 6.97 (dt, J = 7.5, 0.9 Hz, 1H), 6.82 (d, J = 8.3 Hz, 2H), 3.39 (s, 3H), 2.64 (t, J = 7.5 Hz, 2H), 1.71–1.61 (m, 2H), 1.34 (tq, J = 7.5, 7.5 Hz, 2H), 0.84 (t, J = 7.3 Hz, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 156.9 (C_q), 146.8 (C_q), 137.7 (C_q), 137.7 (C_q), 131.3 (CH), 131.0 (CH), 128.7 (CH), 128.2 (CH), 123.6 (CH), 120.7 (CH), 116.8 (C_q), 111.2 (CH), 54.9 (CH_3), 31.5 (CH_2), 24.8 (CH_2), 22.3 (CH_2), 13.7 (CH_3).
IR (KBr): 3853, 3744, 2956, 2361, 1653, 1559, 1506, 1457, 1248, 994, 757, 689, 522 cm^{-1}.
MS (EI) *m/z* (relative intensity) 307 (5) [M^+], 279 (55), 236 (100), 133 (25), 105 (34), 77 (23).
HR-MS (ESI) *m/z* calcd for $C_{19}H_{22}N_3O$ 308.1757, found 308.1757.

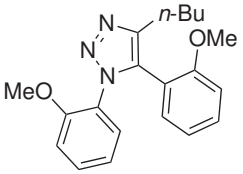
Synthesis of 4-*n*-butyl-5-(4-methoxyphenyl)-1-(2-methoxyphenyl)-1*H*-1,2,3-triazole (40f)



The representative procedure H was followed, using 4-*n*-butyl-1-(2-methoxyphenyl)-1*H*-1,2,3 triazole (**37f**) (231 mg, 1.00 mmol), 4-iodoanisole (**77a**) (702 mg, 3.00 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). After 20 h, purification by chromatography (*n*-hexane/EtOAc: 9/1 → 7/1 → 5/1 → 4/1) yielded **40f** (219 mg, 65%) as a light-yellow solid. m.p. 88–90 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.37–7.32 (m, 2H), 7.03 (d, J = 8.8 Hz, 2H), 6.98

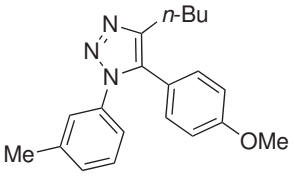
(m, 1H), 6.84 (m, 1H), 6.79 (d, J = 8.8 Hz, 2H), 3.75 (s, 3H), 3.47 (s, 3H), 2.72 (t, J = 7.6 Hz, 2H), 1.76–1.66 (m, 2H), 1.35 (tq, J = 7.5, 7.5 Hz, 2H), 0.87 (t, J = 7.3 Hz, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 159.5 (C_q), 153.7 (C_q), 144.6 (C_q), 135.4 (C_q), 130.9 (CH), 130.0 (CH), 128.6 (CH), 126.0 (C_q), 120.7 (CH), 120.2 (C_q), 113.7 (CH), 112.1 (CH), 55.4 (CH_3), 55.1 (CH_3), 31.8 (CH_2), 25.0 (CH_2), 22.5 (CH_2), 13.8 (CH_3).
IR (KBr): 3859, 3435, 2956, 1615, 1507, 1467, 1284, 1251, 1178, 1022, 836, 757 cm^{-1}.
MS (EI) m/z (relative intensity) 337 (7) [M$^+$], 309 (44), 266 (62), 133 (100), 77 (10).
HR-MS (ESI) m/z calcd for $C_{20}H_{24}N_3O_2$ 338.1863, found 338.1863.

Synthesis of 4-*n*-butyl-1,5-bis(2-methoxyphenyl)-1*H*-1,2,3-triazole (40g)



The representative procedure H was followed, using 4-*n*-butyl-1-(2-methoxyphenyl)-1*H*-1,2,3 triazole (**37f**) (231 mg, 1.00 mmol), 2-iodoanisole (**77b**) (702 mg, 3.00 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). After 20 h, purification by chromatography (*n*-hexane/EtOAc: 7/1 → 5/1 → 4/1) yielded **40g** (225 mg, 68%) as a colorless oil.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.35 (dd, J = 7.8, 1.8 Hz, 1H), 7.31–7.23 (m, 2H), 7.04 (dd, J = 7.5, 1.7 Hz, 1H), 6.94 (dt, J = 7.7, 1.3 Hz, 1H), 6.87 (dt, J = 7.5, 1.1 Hz, 1H), 6.78 (m, 2H), 3.52 (s, 3H), 3.45 (s, 3H), 2.64 (t, J = 7.6 Hz, 2H), 1.72–1.62 (m, 2H), 1.33 (tq, J = 7.5, 7.5 Hz, 2H), 0.84 (t, J = 7.3 Hz, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 157.0 (C_q), 153.5 (C_q), 145.8 (C_q), 132.8 (C_q), 131.2 (CH), 130.4 (CH), 130.3 (CH), 128.3 (CH), 126.5 (C_q), 120.3 (CH), 120.1 (CH), 117.2 (C_q), 111.8 (CH), 110.7 (CH), 55.3 (CH_3), 54.9 (CH_3), 31.4 (CH_2), 25.0 (CH_2), 22.4 (CH_2), 13.8 (CH_3).
IR (KBr): 3439, 2956, 2871, 1736, 1603, 1509, 1466, 1284, 1249, 1163, 1025, 755 cm^{-1}.
MS (EI) m/z (relative intensity) 337 (7) [M$^+$], 309 (56), 266 (100), 253 (10), 133 (18), 105 (26), 77 (8).
HR-MS (ESI) m/z calcd for $C_{20}H_{24}N_3O_2$ 338.1863, found 338.1862.

Synthesis of 4-*n*-butyl-5-(4-methoxyphenyl)-1-(*m*-tolyl)-1*H*-1,2,3-triazole (40h)



The representative procedure H was followed, using 4-*n*-butyl-1-(*m*-tolyl)-1*H*-1,2,3 triazole (**37e**) (230 mg, 1.00 mmol), 4-iodoanisole (**77a**) (702 mg, 3.00 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). After 20 h purification by column chromatography (*n*-hexane/EtOAc: 12/1 → 10/1) yielded **40h** (237 mg, 70 %) as an off-white solid. m.p. 92–94 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.21–7.12 (m, 3H), 7.05 (td, J = 8.8, 2.1 Hz, 2H), 6.93 (m, 1H), 6.86 (td, J = 8.8, 2.2 Hz, 2H), 3.79 (s, 3H), 2.69 (t, J = 7.6 Hz, 2H), 2.31 (s, 3H), 1.73–1.63 (m, 2H), 1.34 (tq, J = 7.5, 7.5 Hz, 2H), 0.86 (t, J = 7.3 Hz, 3H).

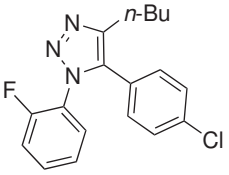
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 159.8 (C_q), 145.9 (C_q), 139.3 (C_q), 136.9 (C_q), 133.6 (C_q), 130.8 (CH), 129.3 (CH), 128.7 (CH), 125.5 (CH), 121.8 (CH), 119.8 (C_q), 114.2 (CH), 55.2 (CH_3), 31.8 (CH_2), 24.9 (CH_2), 22.4 (CH_2), 21.2 (CH_3), 13.8 (CH_3).

IR (KBr): 2955, 2859, 1737, 1613, 1507, 1293, 1252, 1178, 1035, 834, 695, 612 cm^{-1}.

MS (EI) *m/z* (relative intensity) 321 (6) [M^+], 293 (37), 250 (50), 133 (100), 91 (15), 77 (4), 65 (10).

HR-MS (ESI) *m/z* calcd for $C_{20}H_{24}N_3O$ 322.1914, found 322.1914.

Synthesis of 4-*n*-butyl-5-(4-chlorophenyl)-1-(2-fluorophenyl)-1*H*-1,2,3-triazole (40i)



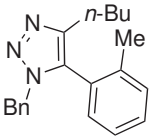
The representative procedure H was followed, using 4-*n*-butyl-1-(2-fluoro phenyl)-1*H*-1,2,3-triazole (**37g**) (226 mg, 1.03 mmol), 4-chloroiodobenzene (**77c**) (717 mg, 3.00 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). After 20 h purification by column chromatography (*n*-hexane/EtOAc: 9/1) yielded **40i** (139 mg, 42%) as a brown oil.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.52–7.39 (m, 2H), 7.32 (d, J = 8.5 Hz, 2H), 7.25 (m, 1H), 7.12 (dd, J = 5.3, 1.3 Hz, 1H), 7.09 (d, J = 8.5 Hz, 2H), 2.72 (t, J = 7.9 Hz, 2H), 1.70 (m, 2H), 1.35 (tq, J = 7.5, 7.5 Hz, 2H), 0.87 (t, J = 7.3 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 155.8 ($^1J_{C–F}$ = 254 Hz, C_q), 145.6 (C_q), 135.1 (C_q),

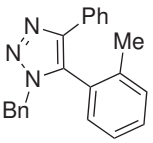
134.4 (C_q), 131.5 ($^3J_{C–F}$ = 8 Hz, CH), 130.1 (CH), 129.0 (CH), 128.5 (CH), 125.7 (C_q), 124.8 ($^4J_{C-F}$ = 4 Hz, CH), 124.6 (C_q), 116.8 ($^2J_{C–F}$ = 19 Hz, CH), 31.6 (CH_2), 24.8 (CH_2), 22.4 (CH_2), 13.8 (CH_3).
IR (ATR): 2945, 2858, 1488, 1458, 1397, 1264, 1230, 1117, 820, 759 cm^{-1}.
MS (EI) *m/z* (relative intensity) 301 (12), 258 (100), 137 (94), 122 (32), 102 (30), 75 (30), 43 (78).
HR-MS (ESI) *m/z* calcd for $C_{18}H_{17}N_3FCl$ 330.1168, found 330.1160.

Synthesis of 1-benzyl-4-*n*-butyl-5-(*o*-tolyl)-1*H*-1,2,3-triazole (40j)



The representative procedure I was followed, using 1-hexyne (**35c**) (82 mg, 1.00 mmol), benzyl azide (**34b**) (133 mg, 1.00 mmol), 2-iodotoluene (**77d**) (654 mg, 3.00 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). Purification by column chromatography (*n*-hexane/EtOAc: 7/1 → 5/1) yielded **40j** (255 mg, 67%) as a bright yellow oil.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.35 (dt, J = 7.5, 1.4 Hz, 1H), 7.23–7.13 (m, 5H), 6.97–6.88 (m, 3H), 5.30–5.18 (m, 2H), 2.59–2.47 (m, 1H), 2.46–2.35 (m, 1H), 1.71 (s, 3H), 1.60–1.50 (m, 2H), 1.31–1.19 (m, 2H), 0.80 (t, J = 7.3 Hz, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 146.3 (C_q), 138.3 (C_q), 134.9 (C_q), 133.4 (C_q), 130.5 (CH), 130.3 (CH), 129.7 (CH), 128.4 (CH), 128.0 (CH), 128.0 (CH), 126.9 (C_q), 125.9 (CH), 52.1 (CH_2), 31.2 (CH_2), 24.9 (CH_2), 22.3 (CH_2), 19.1 (CH_3), 13.7 (CH_3).
IR (KBr): 3064, 3032, 2955, 2931, 2859, 1739, 1496, 1456, 1217, 1014 cm^{-1}.
MS (EI) *m/z* (relative intensity) 305 (15) [M^+], 263 (16), 186 (6), 130 (10), 91 (100).
HR-MS (ESI) *m/z* calcd for $C_{20}H_{24}N_3$ 306.1965, found 306.1966.

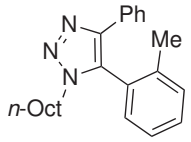
Synthesis of 1-benzyl-4-phenyl-5-(*o*-tolyl)-1*H*-1,2,3-triazole (40k)



The representative procedure I was followed, using phenylacetylene (**35a**) (102 mg, 1.00 mmol), benzyl azide (**34b**) (133 mg, 1.00 mmol), 2-iodotoluene (**77d**) (654 mg, 3.00 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). Purification by column chromatography (*n*-hexane/EtOAc: 7/1 → 5/1) yielded **40k** (228 mg, 70%) as a yellow solid. m.p. 75–77 °C.

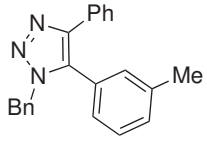
^{1}H-NMR (300 MHz, $CDCl_3$): δ= 7.60–7.56 (m, 2H), 7.46 (dt, J = 7.5, 1.4 Hz, 1H), 7.36–7.21 (m, 8H), 7.14 (dd, J = 7.6, 1.2 Hz, 1H), 7.01–6.97 (m, 2H), 5.39–5.36 (m, 2H), 1.66 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ= 144.4 (C_q), 138.5 (C_q), 134.7 (C_q), 132.8 (C_q), 131.1 (C_q), 130.7 (CH), 130.3 (CH), 130.1 (CH), 128.5 (CH), 128.5 (CH), 128.2 (CH), 128.1 (CH), 127.6 (CH), 127.4 (C_q), 126.5 (CH), 125.7 (CH), 52.2 (CH_2), 19.1 (CH_3).
IR (KBr): 3853, 3688, 2360, 1811, 1700, 1605, 1497, 1457, 1354, 984 cm^{-1}.
MS (EI) m/z (relative intensity) 325 (54) [M$^+$], 206 (71), 179 (13), 91 (100), 65 (6).
HR-MS (ESI) m/z calcd for $C_{22}H_{20}N_3$ 326.1652, found 326.1654.
The spectral data are in accordance with those reported in the literature.[63]

Synthesis of 1-*n*-octyl-4-phenyl-5-(*o*-tolyl)-1*H*-1,2,3-triazole (40l)



The representative procedure I was followed, using phenylacetylene (**35a**) (102 mg, 1.00 mmol), 1-*n*-octyl azide (**34c**) (155 mg, 1.00 mmol), 2-iodotoluene (**77d**) (654 mg, 3.00 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). Purification by column chromatography (*n*-hexane/EtOAc: 10/1 → 7/1) yielded **40l** (239 mg, 69%) as a bright yellow oil.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.53–7.49 (m, 2H), 7.43 (m, 1H), 7.36–7.31 (m, 2H), 7.26–7.19 (m, 4H), 4.17–3.95 (m, 2H), 1.98 (s, 3H), 1.77–167 (m, 2H), 1.26–1.17 (m, 10H), 0.83 (t, J = 6.8 Hz, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 144.0 (C_q), 138.0 (C_q), 132.7 (C_q), 131.3 (C_q), 130.9 (CH), 130.4 (CH), 130.0 (CH), 128.5 (CH), 127.7 (C_q), 127.5 (CH), 126.7 (CH), 125.8 (CH), 48.1 (CH_2), 31.7 (CH_2), 29.8 (CH_2), 28.9 (CH_2), 28.8 (CH_2), 26.4 (CH_2), 22.5 (CH_2), 19.5 (CH_3), 14.0 (CH_3).
IR (KBr): 3062, 2926, 2856, 1605, 1506, 1457, 1356, 1025, 981, 777 cm^{-1}
MS (EI) m/z (relative intensity) 347 (43) [M$^+$], 319 (9), 207 (100), 179 (18), 43 (12).
HR-MS (ESI) m/z calcd for $C_{23}H_{30}N_3$ 348.2434, found 348.2432.

Synthesis of 1-benzyl-4-phenyl-5-(*m*-tolyl)-1*H*-1,2,3-triazole (40m)



The representative procedure I was followed, using phenylacetylene (**35a**) (102 mg, 1.00 mmol), benzyl azide (**34b**) (133 mg, 1.00 mmol), 3-iodotoluene (**77e**) (654 mg, 3.00 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). Purification by column chromatography (*n*-hexane/EtOAc: 10/1 → 7/1 → 5/1) yielded **40m** (199 mg, 61%) as a yellow solid. m.p. 92–95 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.56–7.53 (m, 2H), 7.30–7.19 (m, 8H), 7.02– 6.99 (m, 2H), 6.92 (m, 1H), 6.85 (s, 1H), 5.36 (s, 2H), 2.27 (s, 3H).

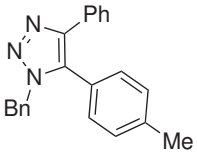
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 144.3 (C_q), 138.9 (C_q), 135.5 (C_q), 134.0 (C_q), 131.0 (C_q), 130.7 (CH), 130.4 (CH), 129.0 (CH), 128.6 (CH), 128.4 (CH), 128.1 (CH), 127.7 (CH), 127.6 (C_q), 127.6 (CH), 127.1 (CH), 126.6 (CH), 52.0 (CH_2), 21.3 (CH_3).

IR (KBr): 3692, 2410, 1607, 1589, 1497, 1478, 1456, 1353, 1074, 996 cm^{-1}.

MS (EI) *m/z* (relative intensity) 325 (36) [M^+], 206 (100), 179 (13), 91 (77), 65 (7).

HR-MS (ESI) *m/z* calcd for $C_{22}H_{20}N_3$ 326.1652, found 326.1654.

Synthesis of 1-benzyl-4-phenyl-5-(*p*-tolyl)-1*H*-1,2,3-triazole (40n)



The representative procedure I was followed, using phenylacetylene (**35a**) (109 mg, 1.07 mmol), benzyl azide (**34b**) (141 mg, 1.06 mmol), 4-iodotoluene (**77f**) (654 mg, 3.00 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). Purification by column chromatography (*n*-hexane/EtOAc: 10/1 → 7/1) yielded **40n** (180 mg, 55%) as an off-white solid. m.p.: 120–122 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.56–7.50 (m, 2H), 7.39 (dt, J = 7.5, 3.8 Hz, 1H), 7.31–7.13 (m, 8H), 7.08 (d, J = 7.5 Hz, 1H), 6.93 (dd, J = 7.6, 1.8 Hz, 2H), 5.30 (d, J = 14.7 Hz, 2H), 1.60 (s, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 144.4 (C_q), 138.4 (C_q), 134.7 (C_q), 132.8 (C_q), 131.1 (C_q), 130.7 (CH), 130.3 (CH), 130.0 (CH), 128.5 (CH), 128.5 (CH), 128.2 (CH), 128.0 (CH), 127.6 (CH), 127.3 (C_q), 126.4 (CH), 125.6 (CH), 52.2 (CH_2), 19.0 (CH_3).

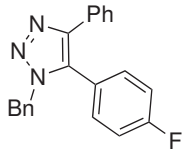
IR (KBr): 3030, 1605, 1500, 1454, 1245, 1027, 948, 758, 693 cm^{-1}.

MS (EI) *m/z* (relative intensity) 325 (31) [M^+], 206 (72), 179 (42), 91 (100), 65 (31).

HR-MS (ESI) *m/z* calcd for $C_{22}H_{19}N_3$ 325.1579, found 325.1565.

The spectral data are in accordance with those reported in the literature.[63]

Synthesis of 1-benzyl-5-(4-fluorophenyl)-4-phenyl-1*H*-1,2,3-triazole (40o)



The representative procedure I was followed, using phenylacetylene (**35a**) (102 mg, 1.00 mmol), benzyl azide (**34b**) (133 mg, 1.00 mmol), 1-fluoro-4-iodobenzene (**77g**) (715 mg, 3.00 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). Purification by chromatography (*n*-hexane/EtOAc: 7/1 → 5/1) yielded **40o** (133 mg, 40%) as a brown solid. m.p.: 95–97 °C.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.53–7.50 (m, 2H), 7.29–7.20 (m, 6H), 7.10–7.08 (m, 4H), 7.02–6.99 (m, 2H), 5.39 (s, 2H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 163.3 (C_q, $^1J_{C–F}$ = 250 Hz), 144.8 (C_q), 135.2 (C_q), 132.8 (C_q), 132.0 (CH, $^3J_{C–F}$ = 8 Hz), 130.7 (C_q), 128.7 (CH), 128.5 (CH), 128.2 (CH), 127.8 (CH), 127.4 (CH), 126.6 (CH), 123.7 (C_q, $^4J_{C–F}$ = 4 Hz), 116.4 (CH, $^2J_{C–F}$ = 21 Hz), 52.1 (CH_2).

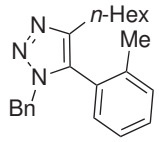
^{19}F-NMR (282 MHz, $CDCl_3$): δ = –110.4 (quint, J = 6.9 Hz).

IR (KBr): 3065, 3034, 1900, 1606, 1515, 1485, 1445, 1354, 1238, 1160 cm^{-1}.

MS (EI) *m/z* (relative intensity) 329 (32) [M^+], 210 (90), 183 (15), 91 (100), 65 (9).

HR-MS (ESI) *m/z* calcd for $C_{21}H_{17}FN_3$ 330.1401, found 330.1400.

Synthesis of 1-benzyl-4-(*n*-hexyl)-5-(*o*-tolyl)-1*H*-1,2,3-triazole (40p)



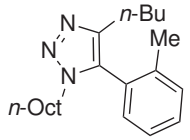
The representative procedure I was followed, using 1-octyne (**35d**) (119 mg, 1.08 mmol), benzyl azide (**34b**) (144 mg, 1.08 mmol), 2-iodotoluene (**77d**) (669 mg, 3.07 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). Purification by column chromatography (*n*-hexane/EtOAc: 10/1 → 7/1 → 5/1) yielded **40p** (204 mg, 60%) as a yellow oil.

^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.34 (m, 1H), 7.24–7.12 (m, 5H), 6.97–6.86 (m, 3H), 5.24 (d, J = 14.8 Hz, 2H), 2.46 (m, 2H), 1.71 (s, 3H), 1.58–1.48 (m, 2H), 1.25–1.13 (m, 6H), 0.79 (t, J = 6.8 Hz, 3H).

^{13}C-NMR (75 MHz, $CDCl_3$): δ = 146.3 (C_q), 138.2 (C_q), 134.9 (C_q), 133.3 (C_q), 130.5 (CH), 130.2 (CH), 129.6 (CH), 128.4 (CH), 128.0 (CH), 127.9 (CH), 126.9 (C_q), 125.9 (CH), 52.1 (CH_2), 31.4 (CH_2), 29.0 (CH_2), 28.9 (CH_2), 25.1 (CH_2), 22.4 (CH_2), 19.1 (CH_3), 13.9 (CH_3).

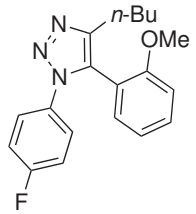
IR (KBr): 2927, 2856, 1606, 1495, 1312, 1214, 1015, 825, 738 cm^{-1}.
MS (EI) *m/z* (relative intensity) 333 (8) [M^+], 263 (12), 214 (4), 91 (100), 43 (16).
HR-MS (ESI) *m/z* calcd for $C_{22}H_{27}N_3$ 333.2205, found 333.2195.
The spectral data are in accordance with those reported in the literature.[63]

Synthesis of 4-*n*-butyl-1-(*n*-octyl-5-(*o*-tolyl)-1*H*-1,2,3-triazole (40q)



The representative procedure I was followed, using 1-hexyne (**35c**) (83 mg, 1.00 mmol), *n*-octyl azide (**34c**) (164 mg, 1.06 mmol), 2-iodotoluene (**77d**) (654 mg, 3.00 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). Purification by chromatography (*n*-hexane/EtOAc: 10/1 → 7/1) yielded **40q** (143 mg, 44%) as a brown oil.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.33 (m, 3H), 7.10 (d, J = 7.5 Hz, 1H), 4.15–3.87 (m, 2H), 2.49 (m, 2H), 2.06 (s, 3H), 1.78–1.47 (m, 4H), 1.33–1.15 (m, 12H), 0.84 (t, J = 6.9 Hz, 3H), 0.81 (t, J = 7.4 Hz, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 146.0 (C_q), 138.1 (C_q), 133.5 (C_q), 130.9 (CH), 130.7 (CH), 129.9 (CH), 127.5 (C_q), 126.4 (CH), 48.3 (CH_2), 31.9 (CH_2), 31.6 (CH_2), 30.1 (CH_2), 29.2 (CH_2), 29.1 (CH_2), 26.6 (CH_2), 25.1 (CH_2), 22.8 (CH_2), 22.6 (CH_2), 19.8 (CH_3), 14.3 (CH_3), 14.0 (CH_3).
IR (KBr): 2925, 2856, 1458, 1378, 1301, 1212, 1013, 757 cm^{-1}.
MS (EI) *m/z* (relative intensity) 327 (28) [M^+], 285 (20), 256 (22), 187 (36), 144 (100), 117 (44), 71 (18), 57 (32), 43 (44).
HR-MS (ESI) *m/z* calcd for $C_{21}H_{33}N_3$+H^+ 328.2747, found 328.2747.

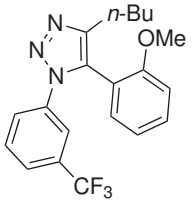
Synthesis of 4-*n*-butyl-1-(4-fluorophenyl)-5-(2-methoxyphenyl)-1*H*-1,2,3-triazole (40r)



The representative procedure J was followed, using 1-fluoro-4-iodobenzene (**77g**) (222 mg, 1.02 mmol), 1-hexyne (**35c**) (84 mg, 1.02 mmol), 2-iodoanisole (**77b**) (732 mg, 3.13 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). Purification by column chromatography (*n*-hexane/EtOAc: 10/1 → 7/1 → 5/1) yielded **40r** (227 mg,

70%) as a yellow oil.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.36 (ddd, J = 8.4, 7.6, 1.8 Hz, 1H), 7.26–7.10 (m, 2H), 7.13 (dd, J = 7.5, 1.8 Hz, 1H), 7.02–6.90 (m, 3H), 6.82 (d, J = 8.3, 1H), 3.43 (s, 3H), 2.61 (t, J = 7.5 Hz, 2H), 1.69–1.58 (m, 2H), 1.34–1.24 (m, 2H), 0.82 (t, J = 7.3 Hz, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 162.0 (C_q, $^1J_{C–F}$ = 247 Hz), 156.8 (C_q), 146.8 (C_q), 133.8 (C_q, $^4J_{C–F}$ = 3 Hz), 131.3 (CH), 131.2 (CH), 131.1 (C_q), 125.4 (CH, $^3J_{C–F}$ = 9 Hz), 120.8 (CH), 116.4 (C_q), 115.7 (CH, $^2J_{C–F}$ = 23 Hz), 111.2 (CH), 54.9 (CH_3), 31.5 (CH_2), 24.7 (CH_2), 22.2 (CH_2), 13.7 (CH_3).
^{19}F-NMR (282 MHz, $CDCl_3$): δ = –112.9 (m).
IR (KBr): 3053, 2958, 2872, 1737, 1605, 1515, 1488, 1467, 1433, 1266, 1110, 739 cm^{-1}.
MS (EI) m/z (relative intensity) 325 (2) [M$^+$], 297 (74), 254 (100), 240 (15), 133 (34), 111 (52), 105 (36), 77 (8).
HR-MS (ESI) m/z calcd for $C_{19}H_{21}FN_3O$ 326.1663, found 326.1663.

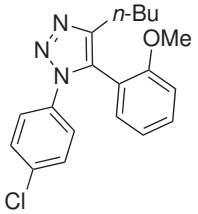
Synthesis of 4-*n*-butyl-5-(2-methoxyphenyl)-1-{3-(trifluoromethyl)phenyl}-1*H*-1,2,3-triazole (40s)



The representative procedure J was followed, using 3-iodobenzotrifluoride (**77i**) (275 mg, 1.01 mmol), 1-hexyne (**35c**) (88 mg, 1.07 mmol), 2-iodoanisole (**77b**) (729 mg, 3.09 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). Purification by column chromatography (*n*-hexane/EtOAc: 7/1 → 5/1) yielded **40s** (144 mg, 38%) as a yellow oil.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.63 (s, 1H), 7.57 (d, J = 6.6 Hz, 1H), 7.49–7.38 (m, 3H), 7.20 (dd, J = 7.5, 1.8 Hz, 1H), 7.03 (td, J = 7.5, 1.0 Hz, 1H), 6.84 (d, J = 8.4 Hz, 1H), 3.41 (s, 3H), 2.71–2.62 (m, 2H), 1.67 (quint, J = 7.2 Hz, 2H), 1.33 (sext, J = 7.6 Hz, 2H), 0.85 (t, J = 7.3 Hz, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 156.8 (C_q), 147.2 (C_q), 138.2 (C_q), 131.5 (C_q, $^2J_{C–F}$ = 32 Hz), 131.4 (CH), 131.3 (CH), 131.2 (C_q), 129.4 (CH), 126.5 (CH), 124.8 (CH, $^3J_{C–F}$ = 4 Hz), 123.4 (C_q, $^1J_{C–F}$ = 272 Hz), 121.0 (CH), 120.7 (CH, $^3J_{C–F}$ = 4 Hz), 116.1 (C_q), 111.2 (CH), 54.8 (CH_3), 31.5 (CH_2), 24.7 (CH_2), 22.2 (CH_2), 13.7 (CH_3).
^{19}F-NMR (282 MHz, $CDCl_3$): δ = –63.0 (s).
IR (KBr): 3053, 2958, 2873, 1738, 1489, 1460, 1324, 1173, 1132, 1071, 895, 739 cm^{-1}.
MS (EI) m/z (relative intensity) 375 (6) [M$^+$], 347 (80), 304 (100), 290 (14), 161 (12),

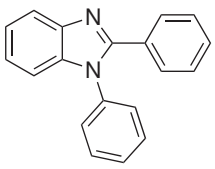
133 (42), 105 (44), 77 (6).
HR-MS (ESI) *m/z* calcd for $C_{20}H_{20}F_3N_3O+H^+$ 376.1631, found 376.1632.

Synthesis of 4-*n*-butyl-1-(4-chlorophenyl)-5-(2-methoxyphenyl)-1*H*-1,2,3-triazole (40t)



The representative procedure J was followed, using 1-chloro-4-iodobenzene (**77j**) (238 mg, 1.00 mmol), 1-hexyne (**35c**) (85 mg, 1.03 mmol), 2-iodoanisole (**77b**) (702 mg, 3.00 mmol), CuI (19.5 mg, 0.10 mmol) and LiO*t*-Bu (160 mg, 2.00 mmol). Purification by column chromatography (*n*-hexane/EtOAc: 9/1 → 7/1) yielded **40t** (228 mg, 67%) as a yellow oil.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.40 (ddd, J = 8.4, 7.6, 1.8 Hz, 1H), 7.30–7.20 (m, 4H), 7.16 (dd, J = 7.5, 1.8 Hz, 1H), 7.01 (dt, J = 7.5, 1.0 Hz, 1H), 6.85 (d, J = 8.3 Hz, 1H), 3.46 (s, 3H), 2.64 (t, J = 7.6 Hz, 2H), 1.66 (quint, J = 7.2 Hz, 2H), 1.38–1.22 (m, 2H), 0.85 (t, J = 7.2 Hz, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 156.8 (C_q), 147.0 (C_q), 136.2 (C_q), 134.0 (C_q), 131.3 (CH), 131.2 (CH), 131.0 (C_q), 128.9 (CH), 124.7 (CH), 120.9 (CH), 116.4 (C_q), 111.2 (CH), 54.9 (CH_3), 31.5 (CH_2), 24.7 (CH_2), 22.3 (CH_2), 13.7 (CH_3).
IR (KBr): 3073, 2956, 2871, 1609, 1499, 1277, 1249, 1163, 1091, 993, 832, 756 cm^{-1}.
MS (EI) *m/z* (relative intensity) 341 (2) [M^+], 315 (16), 313(52), 270 (84), 256 (10), 164 (18), 133 (54), 105 (100), 91 (20), 75 (24).
HR-MS (ESI) *m/z* calcd for $C_{19}H_{21}ClN_3O$ 342.1368, found 342.1369.

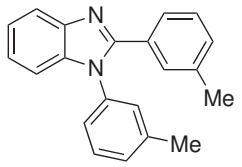
Synthesis of 1,2-diphenyl-1*H*-benzo[*d*]imidazole (84a)



The representative procedure K was followed, using benzimidazole (**83**) (118 mg, 1.00 mmol), iodobenzene (**77h**) (1.02 g, 5.00 mmol), CuI (38.6 mg, 0.20 mmol) and LiO*t*-Bu (240 mg, 3.00 mmol). After 22 h, purification by chromatography (*n*-hexane/EtOAc: 5/1) yielded **84a** (208 mg, 77%) as a colorless solid. m.p. 110 °C. Lit.:[132] 109–110 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.88 (m, 1H), 7.58–7.54 (m, 2H), 7.52–7.44 (m, 3H),

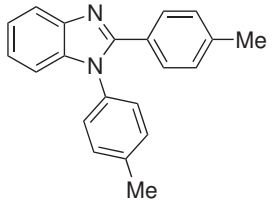
7.36–7.22 (m, 8H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 152.3 (C_q), 142.9 (C_q), 137.1 (C_q), 136.9 (C_q), 129.9 (C_q), 129.8 (CH), 129.4 (CH), 129.4 (CH), 128.5 (CH), 128.2 (CH), 127.4 (CH), 123.3 (CH), 122.9 (CH), 119.8 (CH), 110.4 (CH).
IR (KBr): 3525, 2333, 1596, 1492, 1477, 1456, 1444, 1328, 1260, 1181, 1077, 976, 832, 764, 751, 707 cm^{-1}.
MS (EI) *m/z* (relative intensity) 270 (88) [M^+], 269 (100), 166 (5), 77 (12), 51 (7).
HR-MS (ESI) *m/z* calcd for $C_{19}H_{15}N_2$ 271.1229, found 271.1229.
The spectral data were in accordance with those reported in the literature.[133]

Synthesis of 1,2-di-*m*-tolyl-1*H*-benzo[*d*]imidazole (84b)



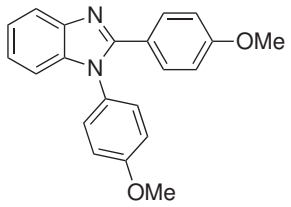
The representative procedure K was followed, using benzimidazole (**83**) (118 mg, 1.00 mmol), 3-iodotoluene (**77e**) (1.10 g, 5.00 mmol), CuI (38.6 mg, 0.20 mmol) and LiO*t*-Bu (240 mg, 3.00 mmol). After 22 h, purification by chromatography (*n*-hexane/EtOAc: 9/1 → 5/1 → 0/1) yielded **84b** (243 mg, 82%) as an off-white solid. m.p. 103–105 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.87 (dt, J = 7.8, 0.8, Hz, 1H), 7.61 (m, 1H), 7.38–7.03 (m, 10H), 2.37 (s, 3H), 2.30 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 152.4 (C_q), 142.9 (C_q), 139.8 (C_q), 138.0 (C_q), 137.2 (C_q), 136.9 (C_q), 130.1 (CH), 130.1 (CH), 129.8 (C_q), 129.5 (CH), 129.2 (CH), 127.8 (CH), 127.7 (CH), 126.2 (CH), 124.5 (CH), 123.1 (CH), 122.7 (CH), 119.6 (CH), 110.4 (CH), 21.3 (CH_3).
IR (KBr): 3779, 2521, 1599, 1490, 1458, 1377, 1326, 1267, 1089, 882, 802, 751, 706 cm^{-1}.
MS (EI) *m/z* (relative intensity) 298 (100) [M^+], 297 (88), 282 (8), 180 (4), 148 (2), 91 (4), 65 (6).
HR-MS (ESI) *m/z* calcd for $C_{21}H_{19}N_2$ 299.1543, found 299.1543.

Synthesis of 1,2-di-*p*-tolyl-1*H*-benzo[*d*]imidazole (84c)



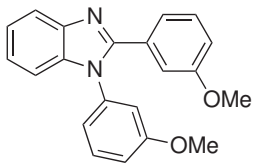
The representative procedure K was followed, using benzimidazole (**83**) (118 mg, 1.00 mmol) and 4-iodotoluene (**77f**) (1.09 g, 5.00 mmol), CuI (38.6 mg, 0.20 mmol) and LiO*t*-Bu (240 mg, 3.00 mmol). After 22 h, purification by chromatography (*n*-hexane/EtOAc: 9/1 → 5/1) yielded **84c** (215 mg, 72%) as an off-white solid. m.p. 108 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.87 (dm, J = 8.0 Hz, 1H), 7.48 (d, J = 8.4 Hz, 2H), 7.34–7.10 (m, 9H), 2.45 (s, 3H), 2.34 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 152.5 (C_q), 142.9 (C_q), 139.4 (C_q), 138.4 (C_q), 137.3 (C_q), 134.4 (C_q), 130.4 (CH), 129.3 (CH), 129.0 (CH), 127.2 (CH), 127.1 (C_q), 123.0 (CH), 122.7 (CH), 119.6 (CH), 110.4 (CH), 21.3 (CH_3), 21.2 (CH_3).
IR (KBr): 3638, 2531, 1609, 1515, 1480, 1453, 1382, 1262, 1185, 1020, 848, 747 cm^{-1}.
MS (EI) *m/z* (relative intensity) 298 (100) [M^+], 297 (86), 282 (4), 180 (6), 149 (3), 116 (3), 91 (6), 65 (8).
HR-MS (ESI) *m/z* calcd for $C_{21}H_{19}N_2$ 299.1543, found 299.1543.

Synthesis of 1,2-di(4-methoxyphenyl)-1*H*-benzo[*d*]imidazole (84d)



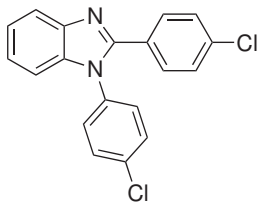
The representative procedure K was followed, using benzimidazole (**83**) (118 mg, 1.00 mmol) and 4-iodoanisole (**77a**) (1.17 g, 5.00 mmol), CuI (38.6 mg, 0.20 mmol) and LiO*t*-Bu (240 mg, 3.00 mmol). After 22 h, purification by chromatography (*n*-hexane/EtOAc: 9/1 → 5/1 → 4/1) yielded **84d** (196 mg, 59%) as an off-white solid. m.p. 150–152 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.85 (d, J = 7.9 Hz, 1H), 7.54 (d, J = 8.9 Hz, 2H), 7.31 (m, 1H), 7.23 (d, J = 8.9 Hz, 2H), 7.23–7.16 (m, 2H), 7.01 (d, J = 8.9 Hz, 2H), 6.83 (d, J = 8.9 Hz, 2H), 3.88 (s, 3H), 3.80 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 160.7 (C_q), 159.6 (C_q), 152.7 (C_q), 143.1 (C_q), 137.8 (C_q), 131.1 (CH), 130.0 (C_q), 128.9 (CH), 123.1 (CH), 122.9 (CH), 122.7 (C_q), 119.7 (CH), 115.2 (CH), 114.0 (CH), 110.6 (CH), 55.5 (CH_3), 55.2 (CH_3).
IR (KBr): 2995, 2838, 2544, 1610, 1455, 1426, 1249, 1181, 1106, 1031, 851, 751 cm^{-1}.
MS (EI) *m/z* (relative intensity) 330 (100) [M^+], 286 (17), 243 (11), 128 (9), 77 (6).
HR-MS (ESI) *m/z* calcd for $C_{21}H_{18}N_2O_2$ 330.1368, found 330.1377.

Synthesis of 1,2-di(3-methoxyphenyl)-1*H*-benzo[*d*]imidazole (84e)



The representative procedure K was followed, using benzimidazole (**83**) (118 mg, 1.00 mmol) and 3-iodoanisole (**77k**) (1.18 g, 5.00 mmol), CuI (38.6 mg, 0.20 mmol) and LiO*t*-Bu (240 mg, 3.00 mmol). After 22 h, purification by chromatography (*n*-hexane/EtOAc: 9/1 → 3/1 → 1/1) yielded **84e** (140 mg, 42%) as a brown solid. m.p. 95–97 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.87 (d, J = 7.9, 1H), 7.37 (dd, J = 8.2, 8.2 Hz, 1H), 7.33–7.24 (m, 3H), 7.22–7.08 (m, 3H), 6.98 (dd, J = 8.1, 2.2 Hz, 1H), 6.88 (dm, J = 7.8 Hz, 2H), 6.84 (dd, J = 2.2, 2.2 Hz, 1H), 3.74 (s, 3H), 3.69 (s, 3H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 160.5 (C_q), 159.3 (C_q), 152.1 (C_q), 142.8 (C_q), 138.0 (C_q), 137.1 (C_q), 131.0 (C_q), 130.5 (CH), 129.2 (CH), 123.3 (CH), 122.9 (CH), 121.8 (CH), 119.8 (CH), 119.6 (CH), 116.1 (CH), 114.3 (CH), 113.9 (CH), 113.0 (CH), 110.5 (CH), 55.5 (CH_3), 55.2 (CH_3).
IR (KBr): 3456, 2364, 1590, 1493, 1457, 1327, 1269, 1241, 1225, 1047, 869, 742 cm^{-1}.
MS (EI) *m/z* (relative intensity) 330 (100) [M^+], 314 (8), 271 (6), 243 (6), 165(4).
HR-MS (ESI) *m/z* calcd for $C_{21}H_{18}N_2O_2$+H^+ 331.1441, found 331.1441.

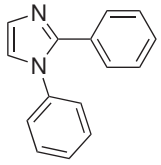
Synthesis of 1,2-di(4-chlorophenyl)-1*H*-benzo[*d*]imidazole (84f)



The representative procedure K was followed, using benzimidazole (**83**) (118 mg, 1.00 mmol) and 4-chloroiodobenzene (**77j**) (1.20 g, 5.00 mmol), CuI (38.6 mg, 0.20 mmol) and LiO*t*-Bu (240 mg, 3.00 mmol). After 22 h, purification by chromatography (*n*-hexane/EtOAc: 5/1) yielded **84f** (210 mg, 62%) as a colorless solid. m.p. 152–155 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.88 (ddd, J = 8.0, 1.3, 0.8 Hz, 1H), 7.53–7.48 (m, 4H), 7.39–7.21 (m, 7H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 151.1 (C_q), 142.9 (C_q), 136.9 (C_q), 135.9 (C_q), 135.2 (C_q), 134.6 (C_q), 130.6 (CH), 130.3 (CH), 128.8 (CH), 128.5 (CH), 128.1 (C_q), 123.8 (CH), 123.3 (CH), 120.0 (CH), 110.2 (CH).
IR (KBr): 3547, 2497, 1595, 1495, 1451, 1409, 1378, 1262, 1199, 1090, 1015, 744 cm^{-1}.

MS (EI) *m/z* (relative intensity) 338 (100) [M^+], 302(12), 166 (6), 111 (6), 75 (8).
HR-MS (ESI) *m/z* calcd for $C_{19}H_{12}Cl_2N_2$+H^+ 339.0450, found 339.0450.

Synthesis of 1,2-diphenyl-1*H*-imidazole (84g)



The representative procedure K was followed, using imidazole (**85**) (68 mg, 1.00 mmol), iodobenzene (**77h**) (1.02 g, 5.00 mmol), CuI (38.6 mg, 0.20 mmol) and LiO*t*-Bu (240 mg, 3.00 mmol). After 22 h, purification by chromatography (*n*-hexane/EtOAc: 7/3) yielded **84g** (94 mg, 43%) as an off-white solid. m.p. 85–87 °C. Lit.:[134] 88–89 °C.
^{1}H-NMR (300 MHz, $CDCl_3$): δ = 7.40–7.36 (m, 5H), 7.29–7.14 (m, 7H).
^{13}C-NMR (75 MHz, $CDCl_3$): δ = 146.6 (C_q), 138.5 (C_q), 130.3 (C_q), 129.4 (CH), 129.0 (CH), 128.5 (CH), 128.2 (CH), 128.1 (CH), 128.0 (CH), 125.8 (CH), 122.8 (CH).
IR (KBr): 3132, 1597, 1493, 1462, 1415, 1313, 1303, 1137, 970, 773, 691 cm^{-1}.
MS (EI) *m/z* (relative intensity) 219 (100) [M-H^+], 193 (25), 178 (17), 117 (19), 90 (33), 77 (52), 51 (38).
HR-MS (ESI) *m/z* calcd for $C_{15}H_{12}N_2$ 220.1000, found 220.0998.
The spectral data were in accordance with those reported in the literature.[135]

6 References

[1] F. Ullmann, *Chem. Ber.* **1903**, *36*, 2382–2384.

[2] F. Ullmann, P. Sponagel, *Chem. Ber.* **1905**, *38*, 2211–2212.

[3] I. Goldberg, *Chem. Ber.* **1906**, *39*, 1691–1692.

[4] L. Ackermann, *Modern Arylation Methods*, Wiley-VCH, Weinheim, **2009**.

[5] A. de Meijere, F. Diederich, *Metal-catalyzed cross-coupling reactions*, 2nd Ed., Wiley-VCH, Weinheim, **2004**.

[6] M. Beller, C. Bolm, *Transition metals for organic synthesis*, 2nd Ed., Wiley-VCH, Weinheim, **2004**.

[7] N. Miyaura, *Top. Curr. Chem* **2002**, *219*, 11–59.

[8] A. F. Littke, G. C. Fu, *Angew. Chem., Int. Ed.* **2002**, *41*, 4176–4211.

[9] J. P. Corbet, G. Mignani, *Chem. Rev.* **2006**, *106*, 2651–2710.

[10] L. Ackermann, *Isr. J. Chem.* **2010**, *50*, 652–663.

[11] L. Ackermann, *Synlett* **2007**, 507–526.

[12] A. Suzuki, *J. Organomet. Chem.* **1999**, *576*, 147–168.

[13] B. H. Lipshutz, S. Ghorai, *Aldrichimica Acta* **2008**, *41*, 59–72.

[14] F. Alonso, I. P. Beletskaya, M. Yus, *Tetrahedron* **2008**, *64*, 3047–3101.

[15] D. S. Surry, S. L. Buchwald, *Angew. Chem., Int. Ed.* **2008**, *47*, 6338–6361.

[16] O. M. Demchuk, B. Yoruk, T. Blackburn, V. Snieckus, *Synlett* **2006**, 2908–2913.

[17] T. E. Barder, S. D. Walker, J. R. Martinelli, S. L. Buchwald, *J. Am. Chem. Soc.* **2005**, *127*, 4685–4696.

[18] S. D. Walker, T. E. Barder, J. R. Martinelli, S. L. Buchwald, *Angew. Chem. Int. Ed.* **2004**, *43*, 1871–1876.

[19] J. Yin, M. P. Rainka, X. X. Zhang, S. L. Buchwald, *J. Am. Chem. Soc.* **2002**, *124*, 1162–1163.

[20] T. Hoshi, I. Saitoh, T. Nakazawa, T. Suzuki, J. i. Sakai, H. Hagiwara, *J. Org. Chem.* **2009**, *74*, 4013–4016.

[21] T. Hoshi, T. Nakazawa, I. Saitoh, A. Mori, T. Suzuki, J. I. Sakai, H. Hagiwara, *Org. Lett.* **2008**, *10*, 2063–2066.

[22] M. G. Organ, S. Calimsiz, M. Sayah, K. H. Hoi, A. J. Lough, *Angew. Chem., Int. Ed.* **2009**, *48*, 2383–2387.

[23] C. Song, Y. Ma, Q. Chai, C. Ma, W. Jiang, M. B. Andrus, *Tetrahedron* **2005**, *61*, 7438–7446.

[24] G. Altenhoff, R. Goddard, C. W. Lehmann, F. Glorius, *J. Am. Chem. Soc.* **2004**, *126*, 15195–15201.

[25] L. Campeau, K. Fagnou, *Chem. Soc. Rev.* **2007**, *36*, 1058–1068.

[26] M. Hapke, L. Brandt, A. Lützen, *Chem. Soc. Rev.* **2008**, *37*, 2782–2797.

[27] K. L. Billingsley, S. L. Buchwald, *Angew. Chem., Int. Ed.* **2008**, *47*, 4695–4698.

[28] J. Z. Deng, D. V. Paone, A. T. Ginnetti, H. Kurihara, S. D. Dreher, S. A. Weissman, S. R. Stauffer, C. S. Burgey, *Org. Lett.* **2009**, *11*, 345–347.

[29] D. X. Yang, S. L. Colletti, K. Wu, M. Song, G. Y. Li, H. C. Shen, *Org. Lett.* **2009**, *11*, 381–384.

[30] D. A. Colby, R. G. Bergman, J. A. Ellman, *Chem. Rev.* **2010**, *110*, 624–655.

[31] L. Ackermann, R. Vicente, A. Kapdi, *Angew. Chem., Int. Ed.* **2009**, *48*, 9792–9826.

[32] P. Thansandote, M. Lautens, *Chem. Eur. J.* **2009**, *15*, 5874–5883.

[33] F. Kakiuchi, T. Kochi, *Synthesis* **2008**, *2008*, 3013–3039.

[34] T. Satoh, M. Miura, *Chem. Lett.* **2007**, *36*, 200–205.

[35] G. Lessene, K. S. Feldman, *in Modern Arene Chemistry*, (Ed.: D. Astruc), Wiley-VCH, Weinheim, **2002**.

[36] V. Y. Trepohl, M. Oestreich, *in Modern Arylation Methods*, (Ed.: L. Ackermann), Wiley-VCH, Weinheim, **2009**.

[37] I. Omae, *Coord. Chem. Rev.* **2004**, *248*, 995–1023.

[38] L. Ackermann, R. Vicente, *Top. Curr. Chem.* **2010**, *292*, 211–229.

[39] S. Oi, Y. Ogino, S. Fukita, Y. Inoue, *Org. Lett.* **2002**, *4*, 1783–1785.

[40] S. Oi, R. Funayama, T. Hattori, Y. Inoue, *Tetrahedron* **2008**, *64*, 6051–6059.

[41] L. Ackermann, A. Althammer, R. Born, *Tetrahedron* **2008**, *64*, 6115–6124.

[42] L. Ackermann, A. Althammer, R. Born, *Synlett* **2007**, 2833–2836.

[43] L. Ackermann, *Org. Lett.* **2005**, *7*, 3123–3125.

[44] L. Ackermann, A. Althammer, R. Born, *Angew. Chem., Int. Ed.* **2006**, *45*, 2619–2622.

[45] L. Ackermann, R. Vicente, A. Althammer, *Org. Lett.* **2008**, *10*, 2299–2302.

[46] L. Ackermann, M. Mulzer, *Org. Lett.* **2008**, *10*, 5043–5045.

[47] J. F. Hartwig, *Organotransition Metal Chemistry: From Bonding to Catalysis*, University Science Books, Sausalito, CA, **2010**.

[48] D. Balcells, E. Clot, O. Eisenstein, *Chem. Rev.* **2010**, *110*, 749–823.

[49] M. Lersch, M. Tilset, *Chem. Rev.* **2005**, *105*, 2471–2526.

[50] V. Ritleng, C. Sirlin, M. Pfeffer, *Chem. Rev.* **2002**, *102*, 1731–1770.

[51] D. H. Ess, W. A. G. III, R. A. Periana, *Organometallics* **2010**, *29*, 6459–6472.

[52] L. Ackermann, *Chem. Rev.* **2011**, *111*, 1315–1345.

[53] D. Lapointe, K. Fagnou, *Chem. Lett.* **2010**, *39*, 1118–1126.

[54] J. Oxgaard, W. J. Tenn, R. J. Nielsen, R. A. Periana, W. A. Goddard, *Organometallics* **2007**, *26*, 1565–1567.

[55] Y. Boutadla, D. L. Davies, S. A. Macgregor, A. I. Poblador-Bahamonde, *Dalton Trans.* **2009**, 5887–5893.

[56] R. Huisgen, *Angew. Chem., Int. Ed.* **1963**, *2*, 565–598.

[57] C. W. Tornoe, C. Christensen, M. Meldal, *J. Org. Chem.* **2002**, *67*, 3057–3064.

[58] V. V. Rostovtsev, L. G. Green, V. V. Fokin, K. B. Sharpless, *Angew. Chem., Int. Ed.* **2002**, *41*, 2596–2599.

[59] L. Zhang, X. Chen, P. Xue, H. H. Y. Sun, I. D. Williams, K. B. Sharpless, V. V. Fokin, G. Jia, *J. Am. Chem. Soc.* **2005**, *127*, 15998–15999.

[60] L. Ackermann, H. K. Potukuchi, *Org. Biomol. Chem.* **2010**, *8*, 4503–4513.

[61] S. Chuprakov, N. Chernyak, A. S. Dudnik, V. Gevorgyan, *Org. Lett.* **2007**, *9*, 2333–2336.

[62] L. Ackermann, R. Vicente, R. Born, *Adv. Synth. Catal.* **2008**, *350*, 741–748.

[63] M. Iwasaki, M. Yorimitsu, K. Oshima, *Chem. Asian J.* **2007**, *2*, 1430–1435.

[64] H.-Q. Do, R. M. K. Khan, O. Daugulis, *J. Am. Chem. Soc.* **2008**, *130*, 15185–15192.

[65] H.-Q. Do, O. Daugulis, *J. Am. Chem. Soc.* **2007**, *129*, 12404–12405.

[66] L. Ackermann, R. Born, *Angew. Chem., Int. Ed.* **2005**, *44*, 2444–2447.

[67] L. Ackermann, R. Born, J. H. Spatz, A. Althammer, C. Gschrei, *Pure Appl. Chem.* **2006**, *78*, 209–214.

[68] L. Ackermann, *Synthesis* **2006**, 1557–1571.

[69] L. Ackermann, A. Althammer, *Chem. Unserer Zeit.* **2009**, *43*, 74–83.

[70] D. X. Yang, S. L. Colletti, K. Wu, M. Song, G. Y. Li, H. C. Shen, *Org. Lett.* **2009**, *11*, 381–384.

[71] D. M. Knapp, E. P. Gillis, M. D. Burke, *J. Am. Chem. Soc.* **2009**, *131*, 6961–6963.

[72] P. Knochel, *Handbook of Functionalized Organometallics*, Wiley-VCH, Weinheim, **2005**.

[73] H. Ila, O. Baron, A. J. Wagner, P. Knochel, *Chem. Commun.* **2006**, 583–593.

[74] C. M. Amb, S. C. Rasmussen, *Eur. J. Org. Chem.* **2008**, 801–804.

[75] K. Tamao, S. Kodama, I. Nakajima, M. Kumada, *Tetrahedron* **1982**, *38*, 3347–3354.

[76] A. Fürstner, A. Leitner, G. Seidel, *Org. Synth.* **2005**, *81*, 33–41.

[77] D. R. Stuart, K. Fagnou, *Aldrichimica Acta* **2007**, *40*, 35–41.

[78] L. Ackermann, A. R. Kapdi, C. Schulzke, *Org. Lett.* **2010**, *12*, 2298–2301.

[79] G. A. Molander, N. Ellis, *Acc. Chem. Res.* **2007**, *40*, 275–286.

[80] G. Y. Li, *Angew. Chem., Int. Ed.* **2001**, *40*, 1513–1516.

[81] G. Y. Li, *J. Org. Chem.* **2002**, *67*, 3643–3650.

[82] U. Christmann, R. Vilar, *Angew. Chem., Int. Ed.* **2005**, *44*, 366–374.

[83] L. Ackermann, H. K. Potukuchi, A. Althammer, R. Born, P. Mayer, *Org. Lett.* **2010**, *12*, 1004–1007.

[84] R. Born, *Doktorarbeit*, Bd. Ludwig-Maximilians-Universität München, **2005**.

[85] L. Ackermann, C. J. Gschrei, A. Althammer, M. Riederer, *Chem. Commun.* **2006**, 1419–1421.

[86] D. Enders, L. Tedeschi, J. W. Bats, *Angew. Chem., Int. Ed* **2000**, *39*, 4605–4607.

[87] X. Linghu, J. R. Potnick, J. S. Johnson, *J. Am. Chem. Soc.* **2004**, *126*, 3070–3071.

[88] H. Kojima, Y. Kinoshita, N. Matsumura, H. Inoue, *J. Heterocycl. Chem.* **1991**, *28*(2059–2060).

[89] L. Ackermann, R. Vicente, N. Hofmann, *Org. Lett.* **2009**, *11*, 4274–4276.

[90] L. Ackermann, H. K. Potukuchi, A. R. Kapdi, C. Schulzke, *Chem. Eur. J.* **2010**, *16*, 3300–3303.

[91] E. Clot, C. Megret, O. Eisenstein, R. N. Perutz, *J. Am. Chem. Soc.* **2009**, *131*, 7817–7827.

[92] K. Shen, Y. Fu, J.-N. Li, L. Liu, Q.-X. Guo, *Tetrahedron* **2007**, *63*, 1568–1576.

[93] L. Ackermann, P. Novák, R. Vicente, V. Pirovano, H. K. Potukuchi, *Synthesis* **2010**, 2245–2253.

[94] L. Ackermann, A. Althammer, S. Fenner, *Angew. Chem., Int. Ed.* **2009**, *48*, 201–204.

[95] B.-T. Guan, X.-Y. Lu, Y. Zheng, D.-G. Yu, T. Wu, K.-L. Li, B.-J. Li, Z.-J. Shi, *Org. Lett.* **2010**, *12*, 396–399.

[96] L. Ackermann, R. Vicente, H. K. Potukuchi, V. Pirovano, *Org. Lett.* **2010**, *12*, 5032–5035.

[97] S. I. Kozhushkov, D. S. Yufit, L. Ackermann, *Org. Lett.* **2008**, *10*, 3409–3412.

[98] A. Prades, M. Poyatos, E. Peris, *Adv. Synth. Catal.* **2010**, *352*, 1155–1162.

[99] R. B. King, P. M. Sundaram, *J. Org. Chem.* **1984**, *49*, 1784–1789.

[100] M. B. Abrams, B. L. Scott, R. T. Baker, *Organometallics* **2000**, *19*, 4944–4956.

[101] H. A. Stefani, C. M. Pereira, R. B. Almeida, R. C. Braga, K. P. Guzen, R. Cella, *Tetrahedron* **2005**, *46*, 6833–6837.

[102] J. C. Antilla, J. M. Baskin, T. E. Barder, S. L. Buchwald, *J. Org. Chem.* **2004**, *69*, 5578–5587.

[103] A. Correa, C. Bolm, *Adv. Synth. Catal.* **2007**, *349*, 2673–2676.

[104] W.-J. Zhou, K.-H. Wang, J.-X. Wang, *Adv. Synth. Catal.* **2009**, *351*, 1378–1382.

[105] N. E. Leadbeater, R. J. Smith, *Org. Lett.* **2006**, *8*, 4589–4591.

[106] G. Ren, X. Cui, Y. Wu, *Eur. J. Org. Chem.* **2010**, 2372–2378.

[107] M. L. N. Rao, D. N. Jadhav, D. Banerjee, *Tetrahedron* **2008**, *64*, 5762–5772.

[108] X.-H. Fan, L.-M. Yang, *Eur. J. Org. Chem.* **2010**, *13*, 2457–2460.

[109] R. Dey, B. Sreedhar, B. C. Ranu, *Tetrahedron* **2010**, *66*, 2301–2305.

[110] M. R. Luzung, J. S. Patel, J. Yin, *J. Org. Chem.* **2010**, *75*, 8330–8332.

[111] L. Wang, Z.-X. Wang, *Org. Lett.* **2007**, *9*, 4335–4338.

[112] L. Ackermann, A. Althammer, *Org. Lett.* **2006**, *8*, 3457–3460.

[113] J. L. Bolliger, C. M. Frech, *Adv. Synth. Catal.* **2010**, *352*, 1075–1080.

[114] H. Erdtman, B. Leopold, *Acta. Chem. Scand.* **1948**, *2*, 34–41.

[115] E. Fillion, D. Fishlock, *J. Am. Chem. Soc.* **2005**, *127*, 13144–13145.

[116] R. Lüdersdorf, J. Mai, K. Präfcke, *Z. Naturforsch., B: J. Chem. Sci.* **1980**, *35*, 1420–1425.

[117] J.-M. Becht, C. L. Drian, *Org. Lett.* **2008**, *10*, 3161–3164.

[118] J. E. Milne, S. L. Buchwald, *J. Am. Chem. Soc.* **2004**, *126*, 13028–13032.

[119] G. A. Molander, D. E. Petrillo, N. R. Landzberg, B. B. J. C. Rohanna, *Synlett* **2005**, 1763–1766.

[120] O. Kobayashi, D. Uraguchi, T. Yamakawa, *Org. Lett.* **2009**, *11*, 2679–2682.

[121] X. Wang, L. Truesdale, J.-Q. Yu, *J. Am. Chem. Soc.* **2010**, *132*, 3648–3649.

[122] R. M. Trend, B. M. Stoltz, *J. Am. Chem. Soc.* **2008**, *130*, 15957–15966.

[123] A. S. Lonkin, W. J. Marshall, Y. Wang, *Organometallics* **2005**, *24*, 619–627.

[124] F. Gellibert, A.-C. de Gouville, J. Wolven, N. Mathews, V.-L. Nguyen, C. Bertho-Rualt, A. Patikis, E. T. Grygielko, N. J. Laping, S. Huet, *J. Med. Chem.* **2006**, *49*, 2210–2221.

[125] P. Gros, Y. Fort, *Synthesis* **1999**, 754–756.

[126] M. G. Organ, M. Abdel-Hadi, S. Avola, N. Hadei, J. Nasielski, C. J. O'Brien, C. Valente, *Chem. Eur. J.* **2006**, *12*, 150–157.

[127] C. Gosmini, S. Lasry, J.-Y. Nedelec, J. Perichon, *Tetrahedron* **1998**, *54*, 1289–1298.

[128] F. Mongin, A.-S. Rebstock, F. Trécourt, G. Quéguiner, F. Marsais, *J. Org. Chem.* **2004**, *69*, 6766–6771.

[129] S.-H. Kim, R. D. Rieke, *Tetrahedron* **2010**, *66*, 3135–3146.

[130] W. Wang, F. Luo, S. Zhang, J. Cheng, *J. Org. Chem.* **2010**, *75*, 2415–2418.

[131] D. Kalyani, N. R. Deprez, L. V. Desai, M. S. Sanford, *J. Am. Chem. Soc.* **2005**, *127*, 7330–7331.

[132] P. Saha, M. A. Ali, P. Ghosh, T. Punniyamurthy, *Org. Biomol. Chem.* **2010**, *8*, 5692–5699.

[133] P. Saha, T. Ramana, N. Purkait, M. A. Ali, R. Paul, T. Punniyamurthy, *J. Org. Chem.* **2009**, *74*, 8719–8725.

[134] R. A. Altman, S. L. Buchwald, *Org. Lett.* **2006**, *8*, 2779–2782.

[135] M. T. Wentzel, J. B. Hewgley, R. M. Kamble, P. D. Wall, M. C. Kozlowski, *Adv. Synth. Catal.* **2009**, *351*, 931–937.

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Sprachkenntnisse

Englisch	flieβend
Deutsch	in Wort und Schrift
Hindi	in Wort und Schrift
Telugu	Muttersprache

Publikationsverzeichnis

- "Mechanistic insight into direct arylations with ruthenium(II) carboxylate catalysts" L. Ackermann, R. Vicente, H. K. Potukuchi, V. Pirovano, *Org. Lett.* **2010**, *12*, 5032–5035.
- "Regioselective syntheses of fully-substituted 1,2,3-triazoles: the CuAAC/C–H bond functionalization nexus" L. Ackermann, H. K. Potukuchi, *Org. Biomol. Chem.* **2010**, *8*, 4503–4513.
- "Ruthenium-catalyzed C–H bond functionalizations of 1,2,3-triazol-4-yl-substituted arenes: Dehydrogenative couplings versus direct arylations" L. Ackermann, P. Novák, R. Vicente, V. Pirovano, H. K. Potukuchi, *Synthesis* **2010**, 2245–2253.
- "Palladium-catalyzed dehydrogenative direct arylations of 1,2,3-triazoles" L. Ackermann, R. Jeyachandran, H. K. Potukuchi, P. Novák, L. Büttner, *Org. Lett.* **2010**, *12*, 2056–2059.
- "Kumada-Corriu cross-couplings with 2-pyridyl Grignard reagents" L. Ackermann, H. K. Potukuchi, A. R. Kapdi, C. Schulzke, *Chem. -Eur. J.* **2010**, *16*, 3300–3303.
- "Tetra-ortho-substituted biaryls through palladium-catalyzed Suzuki-Miyaura couplings with a Diaminochlorophosphine ligand" L. Ackermann, H. K. Potukuchi, A. Althammer, R. Born, P. Mayer, *Org. Lett.* **2010**, *12*, 1004–1007.
- "Palladium-catalyzed cross-coupling reactions of 2-pyridylborates with air-stable HASPO preligands" L. Ackermann, H. K. Potukuchi, *Synlett* **2009**, 2852–2856.
- "Copper-catalyzed N-arylation/hydroamin(d)ation domino synthesis of indoles and its application to the preparation of a Chek1/KDR kinase inhibitor pharmacophore" L. Ackermann, S. Barfüβer, H. K. Potukuchi, *Adv. Synth. Catal.* **2009**, *351*, 1064–1072.
- "Copper-catalyzed "Click" reaction/direct arylation sequence: Modular syntheses of 1,2,3-triazoles" L. Ackermann, H. K. Potukuchi, D. Landsberg, R. Vicente, *Org. Lett.* **2008**, *10*, 3081–3084.
- "Synthesis of an indole containing KDR kinase inhibitor by tandem Sonogashira coupling-5-endo-dig-cyclization as a key step" S. S. Palimkar, V. S. More, P. H. Kumar, K. V. Srinivasan, *Tetrahedron* **2007**, *63*, 12786–1279.
- "Copper-, ligand- and solvent-free synthesis of ynones by coupling acid chlorides with terminal alkynes" S. S. Palimkar, P. H. Kumar, N. R. Jogdand, T. Daniel, R. J. Lahoti, K. V. Srinivasan, *Tetrahedron Letters* **2006**, *47*, 5527–5530.

- "Ligand-, copper-, and amine-free one-pot synthesis of 2-substituted indoles via Sonogashira coupling 5-endo-dig cyclization" S. S. Palimkar, P. H. Kumar, R. J. Lahoti, K. V. Srinivasan, *Tetrahedron*, **2006** *62*, 5109–5115.

Book chapter

- "Syntheses via C-H Bond Functionalizations", L. Ackermann, A. R. Kapdi, H. K. Potukuchi, S. I. Kozhushkov in Handbook of Green Chemistry (Volume-Eds.: C.-J. Li, B. M. Trost), Wiley-VCH, 2011, Weinheim, *in press.*

Posterpräsentationen

- "Ruthenium catalyzed direct arylations through C–H bond cleavages" E. Diers, H. K. Potukuchi, R. Vicente, L. Ackermann. NiKaS Symposium, Göttingen, October **2010**.
- "Transition-metal catalyzed direct arylations through C–H bond cleavages" H. K. Potukuchi, R. Vicente, L. Ackermann. CaRLa Winter School, Heidelberg, March **2010**.
- "Palladium-catalyzed cross-couplings of 2-pyridyl borates using air stable HASPO preligands" H. K. Potukuchi, L. Ackermann. Heidelberg Forum of Molecular Catalysis, Heidelberg, November **2009**.
- "Copper-catalyzed "Click" reaction/direct arylation sequence: Modular syntheses of 1,2,3-triazoles" H. K. Potukuchi, D. Landsberg, R. Vicente, L. Ackermann. ORCHEM 2008, Weimar, September **2008**.
- "Copper-catalyzed "Click" reaction/direct arylation sequence: Modular syntheses of 1,2,3-triazoles" H. K. Potukuchi, D. Landsberg, R. Vicente, L. Ackermann. Jung Chemiker Forum, Göttingen, June **2008**.
- "Ligand-, copper- and amine- free one-pot synthesis of 2-substituted indoles via tandem Sonogashira coupling 5-endo-dig cyclization" S. S. Palimkar, P. H. Kumar, R. J. Lahoti, K. V. Srinivasan. ACS-CSIR Joint International Conference, Pune, India, January **2006**.
- "Ligand free Suzuki coupling reaction at ambient conditions under ultrasound irradiation" K. Venkatesan, P. H. Kumar, R. J. Lahoti, T. Daniel, K. V. Srinivasan. ACS-CSIR Joint International Conference, Pune, India, January **2006**.