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Efficient synthesis of racemic and chiral alkenyl sulfoxides by palladium-catalyzed Suzuki coupling

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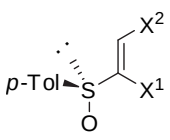
ABSTRACT

Alkenyl sulfoxide derivatives are obtained in high yields through a palladium-catalyzed Suzuki/Miyaura cross-coupling reaction of racemic and chiral 1-halo sulfoxides with aryl and alkenyl boronic acids. Chiral substrates react with no loss of optical purity and high optical yields. The reaction takes place with different palladium catalysts, such as $Pd(PPh_3)_4$ or $Pd(OAc)_2$/DABCO. Although nitrogen ligands like DABCO lead to an active palladium catalyst, they are less effective than the phosphine ones.

1. Introduction

Alkenyl sulfoxides are useful synthetic intermediates in organic chemistry,[1] and are widely used as dienophiles,[2] dipolarophiles,[3] Michael acceptors,[4] substrates for Claisen rearrangements,[5] as well as in transition metal-catalyzed processes, such as Heck[6] or Pauson/Khand reactions.[7] Besides, specific applications like key building blocks in the synthesis of fine chemicals, such as alkaloid aspidoespermidina[1c] or antibiotic TAN-1085,[8] have been described. Because of their valuable intermediacy, especially in asymmetric synthesis, different approaches for the synthesis of this class of compounds are known. Among them, the oxidation of the corresponding sulfides,[9] the condensation of carbonyl compounds,[10] the hydrogenation of alkynyl sulfoxides[11] and the Andersen synthesis[12] are the most representative. However, these procedures approve to be rather complicated and usually require the use of multi-step protocols or expensive reagents. Nevertheless, continued efforts made in this field have resulted in new strategies for the regio- and stereoselective synthesis of some interesting alkenyl sulfoxides.[1a] Surprisingly, transition-metal catalyzed cross-coupling methodologies[13] have scarcely been applied to prepare alkenyl sulfoxides despite the substrates containing this functional group proving efficient partners for different types of coupling reactions.[14,15] The synthetic interest of the target alkenyl sulfoxides prompted us to explore the cross-coupling methodology using halovinyl sulfoxides as suitable starting materials. Moreover, halovinyl sulfoxides may be envisaged as synthetic equivalents of vinyl bromides if the sulfinyl moiety is removed.[16]

Although atomic economy is indeed a drawback in this approach, the high toxicity of vinyl bromides justifies the search of safer alternatives. In order to outline the reactivity profile of this class of compounds in cross-coupling reactions, simple halovinyl sulfoxides **1a**–**d** can be selected as representative substrates (Chart 1). Even though 2-bromovinyl sulfoxide **1c** has been used in Stille and Sonogashira[17] cross-coupling processes, there are no precedents of the participation of 1-bromovinyl sulfoxide **1a** in cross-coupling reactions in the literature. Stille coupling processes with 1-iodovinyl derivative **1b**, as described in the literature, proceeds with moderate yields,[17] but the analogous bromovinyl derivative **1a** does not react in the same coupling reaction.[17] As far as we know, this is the only work on the behavior of 1-bromovinyl sulfoxide **1a** in a cross-coupling process in the literature. Therefore, those precedents relating to the structurally similar compounds 1-iodovinyl sulfoxide (**1b**) and



Sulfoxide	X^1	X^2	Stille	Sonogashira
(*S*)-**1a**	Br	H	no	no
(*S*)-**1b**	I	H	yes	no
(*R*)-**1c**	H	Br	yes	yes
(*R*)-**1d**	H	I	yes	yes

Chart 1. Resume of reactivity of 1- and 2-halovinyl sulfoxides according to Ref. 17.

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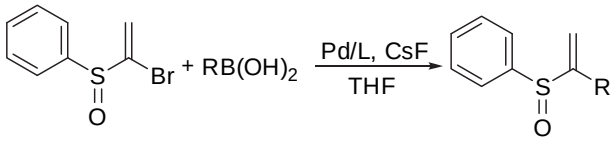
2-bromovinyl sulfoxide (**1c**) deal with only Stille-type coupling reactions.[17] Nowadays however, we considered that the use of organotin compounds is not the first choice of organometallic partners in coupling processes owing to the usual difficulties in the work up and the subsequent isolation of the coupled products, and given the toxicity of these reagents. In contrast, the organoboron derivatives used in Suzuki cross-coupling reactions are not toxic, are not air- and water-sensitive, and the only limitation is their lower reactivity as transmetallating reagents. This disadvantage is overcome by the addition of a base[18] to activate the transmetallation step. In addition, our previous experience with related bromomethyl sulfoxides has proved that Suzuki-type couplings lead to better results than other organometallic compounds.[15] Consequently, the preparation of alkenyl sulfoxides using the 1-bromovinyl sulfoxide **1a** reaction as an electrophile partner in a transition-metal catalyzed cross-coupling process remains unexplored. These facts prompted us to explore the reactivity of 1-bromovinyl sulfoxides in cross-coupling reactions.

2. Results and discussion

Racemic bromosulfoxide **1e** was selected as a benchmark substrate for screening experiments. The synthesis of bromovinyl sulfoxides, such as **1e** by consecutive bromination, and DBU dehydrobromination from the corresponding commercially available vinyl sulfoxide, have been previously reported,[19] although experimental details were not provided. In our study, good yields were attained by the slow addition of the starting material over a long period (18 h) and by carefully controlling the temperature (see the Experimental section) to avoid the formation of significant amounts of 1-bromovinyl sulfide.

Bromovinyl sulfoxide **1e** was tested in palladium-catalyzed Suzuki/Miyaura cross-coupling reactions (see Table 1). As a first experiment, the reaction of 1-bromovinyl sulfoxide **1e** with phenyl boronic acid **2a** took place under mild conditions to give the cross-coupled product **3ea** with a high yield (Table 1, entry 1). The generality of this reaction allowed us to couple this substrate with a variety of aryl and alkenyl boronic acids to afford the corresponding styrene and diene derivatives **3a**–**l**. Very high yields of the cross-coupled products **3** were obtained from the aryl boronic acids activated by electron donor substituents **2b** and **2c** (Table 1, entries 2 and 3). *o*-Substituted boronic acids with moderate steric hindrance (**2f** and **2g**) (Table 1, entries 6 and 7) also gave satisfactory results. With crowded *o*-substituted aryl boronic acid **2h** (Table 1, entry 8), the yield of the coupled product **3eh** was still good (68%). As expected the aryl boronic acids containing electron withdrawing groups (**2d**, **2e**, **2i**, and **2j**) were less effective. Yet even in these less favorable cases, the corresponding cross-coupling products were obtained with good (Table 1, entries 4 and 10) to moderate yields (Table 1, entries 5 and 9).

Table 1
Palladium-catalyzed Suzuki cross-coupling of racemic bromosulfoxide **1e** with boronic acids



1e **2a-l** **3ea-el**

Entry	2	R	Method	3 (Yield)[a]
1	**a**	C_6H_5	A	84
2	**b**	4-$MeOC_6H_4$	A	89
3	**c**	4-MeC_6H_4	A	85
4	**d**	4-$CF_3C_6H_4$	A	75
5	**e**	3-$NO_2C_6H_4$	A	53
6	**f**	2-$MeOC_6H_4$	A	90
7	**g**	2-MeC_6H_4	A	87
8	**h**	2-(^{t}BuCONH)C_6H_4	A	68
9	**i**	2-$CF_3C_6H_4$	A	68
10	**j**	2-BrC_6H_4	A	80
11	**k**	*trans*-1-Hexen-1-yl	A	85
12	**l**	*trans*-Styryl	A	[b]
13	**a**	C_6H_5	B	43
14	**b**	4-$MeOC_6H_4$	B	78
15	**c**	4-MeC_6H_4	B	70
16	**d**	4-$CF_3C_6H_4$	B	23

[a] Isolated yields, A: $Pd(PPh_3)_4$ (10 mol %), 65 °C, 3 h, B: Pd $(OAc)_2$/DABCO (10 mol %), 85 °C, 18 h.
[b] conversion >90%, unstable product.

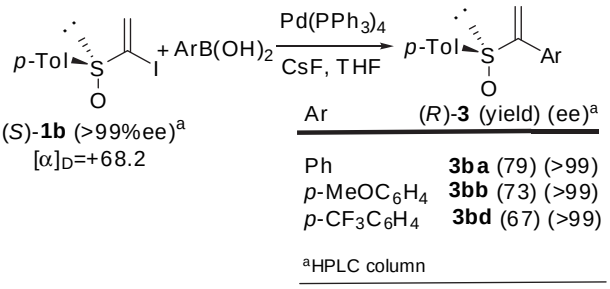
Alkenyl boronic acids **2k** and **2l** were also tested in the cross-coupling reaction. The corresponding dienes, **3ek** and **3el**, were obtained with excellent yields, as detected by ^{1}H NMR of the crude reaction mixture. However, the low stability of diene **3el** did not allow its isolation and complete characterization. These results show that 1-bromovinyl sulfoxide **1e** is a suitable partner in the cross-coupling process that can react efficiently with aryl and alkenyl boronic acids under mild conditions (65 °C, 3 h) using Pd $(PPh_3)_4$, the most common palladium catalyst. Under our conditions, CsF efficiently promotes the transmetallation of boronic acids. We also tested other usual inorganic bases and alcoholic/aqueous solvents employed in Suzuki-type couplings.[20] Nevertheless in this case, bases such as NaOH, $NaHCO_3$, K_3PO_4, and solvents like CH_3OH or the mixture CH_3OH/H_2O were ineffective given the occurrence of Michael-type additions of hydroxyl or alkoxy anions to vinyl sulfoxide **1e**. In addition, Cs_2CO_3 prompted the formation of sulfenic acid derivatives by the decomposition of **1e**, resulting in lower coupling product yields.

Despite the fact that phosphines are the most common ligands in palladium cross-coupling processes in homogeneous media, the problems associated with their incompatibilities with air and aqueous solvents prompted us to test other palladium catalytic systems.[21] Nitrogen ligands are an alternative to phosphine ligands given their economy and availability.[22] However, they are less effective for both the stabilization of the Pd(0) species (which precludes the inactivation of metal, such as black palladium) and the activation of the oxidative addition and reductive elimination steps. Even though, palladium-nitrogen catalysts are still effective when applied to substrates that do not require forcing reaction conditions. Along these lines, DABCO[23] has recently been described as a suitable ligand for the palladium-catalyzed Suzuki synthesis of biaryls. Nevertheless, the cross-coupling of vinyl sulfoxide **1e** with aryl boronic acids **2a**–**d** (Table 1, entries 13–16, method B) was less productive under the $Pd(OAc)_2$/DABCO catalyst and prolonged reaction times were required to achieve moderate conversions. A further decrease of catalyst activity was observed with the less reactive electron-deficient boronic acid **2d** (Table 1, entry 16), in which case the cross-coupled product was obtained with merely a 23% yield. While the inactivated phenyl boronic acid **2a** gave a moderate yield (Table 1, entry 13), boronic acids **2b** and **2c**, containing electron donor substituents, produced high coupling product yields (Table 1, entries 14 and 15).

Next we assayed the cross-coupling reaction using a heterogeneous catalyst given its advantages, these being easy product separation and recycling possibilities. Some commercial heterogeneous catalysts, such as Fibrecat® and Pd Encat®, were checked with 1-bromovinyl sulfoxide **1e**, but none effectively promoted Suzuki reaction.

Thanks to the efficiency of palladium-catalyzed cross-coupling, we extended the method to chiral sulfoxides. The preparation of the required enantiopure bromosulfoxide (*S*)-**1a**, which entailed following the same procedure for the synthesis of racemic **1e**, took place with only a moderate optical yield (66% ee). It is likely that

failure lies in slow bromination because of the π-deficient character of the vinyl sulfoxide, which allows bromination at the sulfur atom with concomitant racemization. Then we prepared 1-iodovinyl sulfoxide (*S*)-**1b**, which we accomplished with both good chemical and optical yields.[17] The palladium-catalyzed cross-coupling reactions of iodovinyl sulfoxide, with a representative neutral, electron-rich and electron-deficient aryl boronic acids, afforded the corresponding 1,1-substituted vinylsulfoxides (*R*)-**3ba**, (*R*)-**3bb**, and (*R*)-**3bd** with good yields in an enantiomerically pure form under the previously optimized conditions (Scheme 1).



Scheme 1. Palladium-catalyzed Suzuki cross-coupling of chiral sulfoxide (*S*)-**1b** with boronic acids.

To conclude, despite other reports in the bibliography about the lack of reactivity of bromovinyl sulfoxides,[17] they are an effective partner for palladium-catalyzed coupling with aryl or alkenyl boronic acids. The synthesis of the alkenyl and dienyl sulfoxide derivatives described herein constitutes a new and valuable route for these compounds with high yields. The transformation is also demonstrated to be efficient for the conversion of enantiopure halovinyl sulfoxides in the corresponding arylated derivatives without modifying optical purity. These results show the compatibility of palladium catalysis with the presence of a chiral sulfinyl moiety in substrates.

3. Experimental section

3.1. General methods and materials

Proton magnetic resonance and carbon magnetic resonance were recorded at 300 MHz and 75 Hz, respectively, with a Bruker AC-300. Chemical shifts are reported in δ parts per million in relation to the TMS peak at 0.0 ppm (^{1}H spectra) and to the $CDCl_3$ peak at 77.0 ppm (^{13}C spectra). High resolution mass spectra were determined on a Fisons VG Autospec instrument. All the melting points were recorded with a Cambridge Instruments apparatus. Reactions were monitored by analytical thin layer chromatography using commercial aluminum sheets pre-coated (0.2 mm layer thickness) with silica gel 60 F_{254} (E. Merck), and visualization was done with short wavelength UV light (254 nm). Product purification by flash chromatography was performed using E. Merck Silica Gel (230–400 mesh). The HPLC tests were carried out with a Chiracel IC column (25×0.46 cm) and hexane: 2-propanol 50:50 as eluents (flow 1.0). Commercial reagents were supplied by Aldrich, except $Pd(PPh_3)_4$ (Johnson Matthey), and they were used without further purification.

3.2. Preparation of starting materials

*3.2.1. (+)-1-Iodo-1-[(S)-p-tolylsulfinyl]ethane ((S)-**1b**)*[17]. Yield 85%; white solid; mp 82–83 °C; ^{1}H NMR ($CDCl_3$) 2.34 (s, 3H), 6.52 (d, *J*=2.9 Hz, 1H), 7.30 (d, *J*=7.9 Hz, 2H), 7.39 (d, *J*=2.9 Hz, 2H), 7.54 (d, *J*=8.2, 2H); ^{13}C NMR ($CDCl_3$) 21.5, 116.8, 125.8, 129.9, 130.4, 138.8, 142.6. $[\alpha]_D^{25}$ +68.0 (*c* 1.35, $CHCl_3$) (lit[17] $[\alpha]_D^{25}$ +68.2 (*c* 1.35, $CHCl_3$)); HPLC (t_R:39.3 min); HRMS (E.I.) *m*/*z* (M^+) 291.9414 (calcd for $C_9H_{10}OSI$ 291.9418).

3.3. Synthesis of 1-bromo phenyl vinyl sulfoxide (1e)

A solution of phenyl vinyl sulfoxide (1 equiv, 50 mmol) in carbon tetrachloride (50 mL) was added dropwise to a solution of bromine (2 equiv, 100 mmol) in carbon tetrachloride (85 mL) cooled at −20 °C in an N_2 atmosphere over an 18-h period. The mixture was stirred at −20 °C for 1 h and then DBU (2 equiv, 100 mmol) dissolved in carbon tetrachloride (30 ml) was added, and the mixture was stirred at room temperature for 30 min. The organic layer was washed with $Na_2S_2O_3$ aqueous satd (50 mL), dried over anhydrous Na_2SO_4, and concentrated to dryness. The crude material was purified by flash column chromatography (hexane/ethyl acetate 30:1) to yield sulfoxide **1a** (65%) colorless oil. ^{1}H NMR ($CDCl_3$) δ 6.15 (d, *J*=3.2 Hz, 1H), 6.83 (d, *J*=3.2 Hz, 1H), 7.44–7.47 (m, 3H), 7.62–7.65 (m, 2H); ^{13}C NMR ($CDCl_3$) 122.2, 125.8, 129.2, 132.0, 136.0, 141.4; HMRS *m*/*z* 229.9392 (calcd for C_8H_7BrOS 229.9400).

3.4. Palladium-catalyzed Suzuki/Miyaura reaction. General procedure A

A mixture of 1-bromo phenyl vinyl sulfoxide **1e** (1 equiv, 0.4 mmol), boronic acid **2** (2eq, 0.8 mmol), CsF (4 equiv, 1.6 mmol), and $Pd(PPh_3)4$ (10 mol %, 0.04 mmol) was added to a flask fitted with degassed and dry THF (6 mL). After being refluxed for 3 h, the reaction mixture was cooled to room temperature, diluted with ethyl acetate (5 mL) and filtered over Celite®. Then the solution was evaporated under reduced pressure. The crude material was purified by flash column chromatography (hexane/ethyl acetate 20:1).

*3.4.1. [1-(Phenylsulfinyl)vinyl]benzene (**3ea**).* Yield: 84%, oil; ^{1}H NMR ($CDCl_3$) 5.84 (s, 1H), 6.17 (s, 1H), 7.12–7.36 (m, 10H); ^{13}C NMR ($CDCl_3$) 116.2, 125.1, 127.5, 128.5, 128.8, 129.0, 131.0, 133.5, 142.6, 154.2; HRMS (E.I.) *m*/*z* (M^+) 228.0617 (calcd for $C_{14}H_{12}OS$ 228.0608).

*3.4.2. 1-Methoxy-4-[(1-phenylsulfinyl)vinyl]benzene (**3eb**).* Yield: 89%, oil; ^{1}H NMR ($CDCl_3$) 3.70 (s, 3H), 5.77 (s, 1H), 6.11 (s, 1H), 7.07 (d, *J*=8.7 Hz, 2H), 7.73 (d, *J*=8.7 Hz, 2H), 7.22–7.38 (m, 5H); ^{13}C NMR ($CDCl_3$) 55.2, 113.9, 115.2, 125.1, 125.8, 128.8, 128.9, 131.0, 142.8, 153.7, 160.1; HRMS (E.I.) *m*/*z* (M^+) 258.0725 (calcd for $C_{15}H_{14}O_2S$ 258.0714).

*3.4.3. 1-Methyl-4-[(1-phenylsulfinyl)vinyl]benzene (**3ec**).* Yield: 85%; oil; ^{1}H NMR ($CDCl_3$) δ 2.25 (s, 3H), 5.82 (s, 1H), 6.16 (s, 1H), 7.00–7.04 (m, 4H), 7.26–7.30 (m, 3H), 7.37–7.40 (m, 2H); ^{13}C NMR ($CDCl_3$) 21.2, 115.6, 125.1, 127.3, 128.8, 129.2, 131.0, 139.0, 142.8, 154.1; HRMS (E.I.) *m*/*z* (M^+) 242.0751 (calcd for $C_{15}H_{14}OS$ 242.0765).

*3.4.4. 1-Trifluoromethyl-4-[(1-phenylsulfinyl)vinyl]benzene (**3ed**).* Yield: 75%; mp55–57 °C; ^{1}H NMR ($CDCl_3$) δ 5.91 (s, 1H), 6.23 (s, 1H), 7.19–7.37 (m, 7H), 7.44–1.47 (m, 2H); ^{13}C NMR ($CDCl_3$) 115.5, 120.1 (q, *J*=223.2 Hz), 125.1, 125.4 (q, *J*=3.8 Hz), 127.9, 129.0, 130.9 (q, *J*=32.7 Hz), 131.4, 137.0, 141.9, 153.3; ^{19}F NMR ($CDCl_3$) δ −73.2; HRMS (E.I.) *m*/*z* (M^+) 296.0456 (calcd for $C_{15}H_{11}F_3OS$ 296.0482).

*3.4.5. 1-Nitro-3-[(1-phenylsulfinyl)vinyl]benzene (**3ee**).* Yield: 53%; ^{1}H NMR ($CDCl_3$) 5.92 (d, *J*=0.7 Hz, 1H), 6.27 (d, *J*=0.7 Hz, 1H), 7.22–7.44 (m, 7H), 7.85 (t, *J*=1.9 Hz, 1H), 8.01 (ddd, *J*=8.1, 2.2, and 1.3 Hz 1H); ^{13}C NMR ($CDCl_3$) 119.6, 112.5, 123.7, 125.1, 129.2, 129.5,

131.7, 133.5, 141.7, 148.0, 152.7; HRMS (E.I.) m/z (M^+) 273.0448 (calcd for $C_{14}H_{11}NO_3S$ 273.0459).

*3.4.6. 1-Methoxy-2-[(1-phenylsulfinyl)vinyl]benzene (**3ef**).* Yield: 90%; oil; ^1H NMR ($CDCl_3$) δ 3.58 (s, 3H), 5.75 (s, 1H), 6.32 (s, 1H), 6.70–6.78 (m, 3H), 7.16–7.30 (m, 6H); ^{13}C NMR ($CDCl_3$) 55.3, 110.7, 117.5, 120.3, 122.4, 125.1, 128.4, 130.4, 130.6, 130.8, 143.0, 152.3, 157.7; HRMS (E.I.) m/z (M^+) 258.0725 (calcd for $C_{15}H_{14}O_2S$ 258.0714).

*3.4.7. 1-Methyl-2-[(1-phenylsulfinyl)vinyl]benzene (**3eg**).* Yield: 87% ; oil; ^1H NMR ($CDCl_3$) δ 1.80 (s, 3H), 5.90 (s, 1H), 6.29 (s, 1H), 6.74 (dd, J=7.4 and 1.1 Hz, 1H), 6.95–7.02 (m, 2H), 7.08–7.29 (m, 6H); ^{13}C NMR ($CDCl_3$) 19.0, 116.9, 124.8, 125.4, 128.6, 128.9, 129.9, 130.1, 131.0, 132.2, 137.0, 141.9, 154.0; HRMS (E.I.) m/z (M^+) 242.0776 (calcd for $C_{15}H_{14}OS$ 242.0765).

*3.4.8. 1-(Pivaloylamino) 2-[(1-phenylsulfinyl)vinyl]benzene (**3eh**).* Yield: 68%; oil; ^1H NMR ($CDCl_3$) 1.13 (s, 9H), 5.74 (s, 1H), 6.36 (s, 1H), 6.47 (dd, J=7.7 Hz, 1H), 6.81 (td, J=7.6 Hz, 1H), 7.19–7.31 (m, 6H), 7.88 (dd, J=8.3 and 0.8 Hz, 1H), 8.42 (s, br s); ^{13}C NMR ($CDCl_3$) 27.5, 39.6, 122.8, 123.4, 123.7, 124.1, 124.6, 128.9, 129.8, 130.3, 131.3, 136.7, 141.0, 153.4, 177.1; HRMS (E.I.) m/z (M^+) 327.1299 (calcd for $C_{19}H_{21}NO_2S$ 327.1293).

*3.4.9. 1-Trifluoromethyl-2-[(1-phenylsulfinyl)vinyl]benzene (**3ei**).* Yield: 80%; mp 77–80 °C; ^1H NMR ($CDCl_3$) δ 5.78 (s, 1H), 6.36 (s, 1H), 6.72 (d, J=7.5 Hz, 1H), 7.23–7.35 (m, 7H), 7.55 (d, J=7.6 Hz, 1H); ^{13}C NMR ($CDCl_3$) 119.2, 123.4 (q, J=274.2 Hz), 126.5 (q, J=5.3 Hz), 127.8 (q, J=5.3 Hz), 128.7, 129.0, 129.7 (q, J=30.4 Hz), 131.1, 131.4, 131.8, 134.6, 141.5, 152.1; ^{19}F NMR ($CDCl_3$) δ −68.1; HRMS (E.I.) m/z (M^+) 296.0468 (calcd for $C_{15}H_{11}F_3OS$ 296.0482).

*3.4.10. 1-Bromo-2-[(1-phenylsulfinyl)vinyl]benzene (**3ej**).* Yield: 80%; oil; ^1H NMR ($CDCl_3$) 5.71 (s, 1H), 6.33 (s, 1H), 6.66–6.69 (m, 1H), 6.98–7.05 (m, 2H), 7.18–7.29 (m, 5H), 7.35–7.40 (m, 1H); ^{13}C NMR ($CDCl_3$) 119.0, 123.5, 125.0, 126.9, 128.76, 130.2, 131.3, 131.4, 132.9, 133.9, 141.7, 153.7; HRMS (E.I.) m/z (M^+) 305.9720 (calcd for $C_{14}H_{11}BrOS$ 305.9713).

*3.4.11. (E)-1(Octa-1,3-dien-2-ylsulfinyl)benzene (**3ek**).* Yield: 85%; oil; ^1H NMR ($CDCl_3$) 0.68 (t, J=7.1 Hz, 3H), 0.95–1.158 (m, 4H), 1.84–1.91 (m, 2H), 5.58 (s, 1H), 5.79–5.85 (m, 3H), 7.12 (s, 1H), 7.30–7.35 (m, 3H), 7.49–7.53 (m, 2H); ^{13}C NMR ($CDCl_3$) 13.8, 22.0, 30.7, 32.7, 115.2, 122.1, 125.5, 129.0, 131.1, 136.9, 143.4, 151.1; HRMS (E.I.) m/z (M^+) 234.1064 (calcd for C_8H_7BrOS 234.1078).

*3.4.12. (R)-1-Methyl-4-(1-phenylvinylsulfinyl)benzene ((R)-**3ba**).* Yield 79%; white solid; mp 105–109 °C; ^1H NMR ($CDCl_3$) 2.24 (s, 3H), 5.84 (s, 1H), 6.17 (s, 1H), 7.04 (d, J=8.0 Hz, 2H), 7.10–7.14 (m, 2H), 7.18–7.20 (m, 3H), 7.25 (d, J=8.2 Hz, 2H); ^{13}C NMR ($CDCl_3$) 21.3, 116.1, 125.4, 127.4, 128.5, 128.9, 129.6, 133.7, 139.4, 141.6, 154.3. $[\alpha]_D$ +117 (c 1.27, $CHCl_3$); HPLC (t_R: 13.8 min); HRMS (E.I.) m/z (M^+) 242.0760 (calcd for $C_{15}H_{14}OS$ 242.0765).

*3.4.13. (R)-1-Methyl-4-(1-(p-tolylsulfinyl)vinil)benzene ((R)-**3bb**).* Yield 73%; white solid; mp 99–103 °C; ^1H NMR ($CDCl_3$) 2.30 (s, 6H), 5.88 (s, 1H), 6.20 (s, 1H), 7.05–7.13 (m, 6H), 7.32 (d, J=8.2 Hz, 2H); ^{13}C NMR ($CDCl_3$) 21.2, 21.4, 115.5, 125.4, 127.3, 129.2, 129.6, 130.9, 138.9, 139.6, 141.6, 154.1. $[\alpha]_D$ +77.6 (c 1.39, $CHCl_3$); HPLC (t_R: 12.4 min); HRMS (E.I.) m/z (M^+) 256.0921 (calcd for $C_{16}H_{16}OS$ 256.0921).

*3.4.14. (R)-1-Methyl-4-(1-(4-(trifluoromethyl)phenyl)vinylsulfinyl) benzene ((R)-**3bd**).* Yield 67%; Orange oil; ^1H NMR ($CDCl_3$) 2.31 (s, 3H), 5.98 (s, 1H), 6.33 (s, 1H), 7.14 (d, J=7.9 Hz, 2H), 7.29–7.34 (m, 4H), 7.52 (d, J=8.09 Hz, 2H); ^{13}C NMR ($CDCl_3$) 21.4, 118.3, 123.1 (q, J=272 Hz), 125.5 (q, J=3.8 Hz), 127.8, 130.3, 130.9 (J_{C-F}=32.6 Hz), 137.3, 138.8, 142.1, 153.4; ^{19}F NMR ($CDCl_3$; 75.5 MHz) −92.9. $[\alpha]_D^{25}$ +71.7 (c 1.4, $CHCl_3$); HPLC (t_R: 8.0 min); HRMS (E.I.) m/z (M^+) 310.0637 (calcd for $C_{16}H_{13}F_3OS$ 310.0639).

3.5. Phosphine-free Suzuki/Miyaura coupling. General procedure B

A mixture of 1-bromo phenyl vinyl sulfoxide **1e** (1 equiv, 0.4 mmol), aryl boronic acid **2** (2q, 0.8 mmol), $Pd(OAc)_2$ (10 mol %), DABCO (20 mol %), CsF (3 equiv) was added to a flask fitted with degassed and dry THF (6 mL), and was stirred at 80 °C for the required time and was monitored by TLC. The reaction mixture was cooled to room temperature, diluted with ethyl acetate (5 mL) and filtered over Celite®. Then the solution was evaporated under reduced pressure. The crude material was purified by flash column chromatography (hexane/ethyl acetate 20:1).

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Supplementary data

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.tet.2010.06.050. These data include MOL files and InChIKeys of the most important compounds described in this article.

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