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Synthesis of Biaryls *via* Nickel-Catalyzed Cross-Coupling Reaction of Arylboronic Acids and Aryl Mesylates

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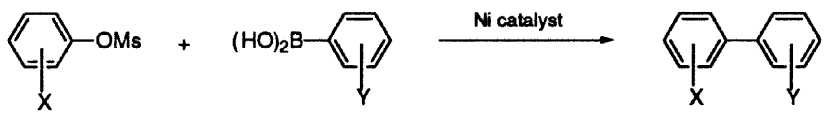
Abstract: *The cross-coupling reaction of arylboronic acids (1.3 equivs) with aryl methanesulfonates was carried out in the presence of a nickel(0) catalyst (3 mol%) and $K_3PO_4 \cdot nH_2O$ (3 equivs). The use of toluene as the solvent and the nickel(0)-dppf catalyst prepared from $NiCl_2$(dppf) plus dppf with BuLi were recognized to be the most efficient to achieve both high yields and high selectivity. The reaction can be applied to various electron-deficient and -rich aryl methanesulfonates to give high yields.*

Palladium complexes are an excellent catalyst for the cross-coupling reaction of arylboronic acids with aryl iodides, bromides or triflates for the synthesis of biaryls.[1] However, an economical reaction by the use of inexpensive substrates and catalysts is desirable for large-scale preparation in industry. Arene chlorides and sulfonates are less expensive, but they have not received much attention because of their low reactivity on the oxidative addition to palladium(0) complexes. In 1995, Percec and co-workers first demonstrated the nickel(0)-catalyzed cross-coupling reaction of arylboronic acids with aryl mesylates.[2] Ni(0)-dppf (1,1'-bis(diphenylphosphino)ferrocene), *in situ* generated by the reduction of $NiCl_2$(dppf) with zinc, was recognized to be the most efficient catalyst and the reaction was highly selective and tolerated various functional groups. Kobayashi demonstrated the efficiency of the boron ate-complexes which *in situ* reduce the $NiCl_2$-phosphine complexes and couple to aryl mesylates at room temperature.[3] The reduction of $NiCl_2$(dppf) with BuLi or DIBAL produced an catalyst which effectively catalyzes the cross-coupling reaction with chloroarenes.[4] The nickel catalyst has an advantage over the palladium because the coupling to the phosphine-bound aryls,[5] which is often unavoidable in the palladium-catalyzed coupling, was not observed.



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Here, we reinvestigated the nickel-catalyzed cross-coupling reaction of arylboronic acids with aryl mesylates which has been limitedly used for the activated aryl mesylates having an electron-withdrawing

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group.[2,3] The reduction of $NiCl_2$(dppf) to the corresponding nickel(0), and the use of K_3PO_4•nH_2O in toluene were found to be essential to achieve high catalyst efficiency, giving high yields for various aryl mesylates having an electron-withdrawing or -donating group (Eq. 1).

Reaction Conditions

The results of the cross-coupling reaction of *o*-tolylboronic acid with aryl mesylates under similar conditions used for chloroarenes[4] and mesylates[2] ($NiCl_2$•dppf/dioxane/80 ℃) are shown in Table 1. The electron-deficient mesylates readily participated in the coupling reaction (entries 1 and 2), but the presence of an electron-donating group greatly reduced the yields of biaryls because of their slow oxidative addition to the nickel(0) complex (entries 3-5). The order of yields was parallel to the Hammett σ- rather than the σ constant, as was previously demonstrated by Milstein in the reaction of chloroarenes with a palladium(0) complex.[6]

Table 1. The Effect of Substituents on the Cross-Coupling Reaction of *o*-Tolylboronic Acid with Aryl Mesylates in Dioxane[a]

entry	XC_6H_4OMs (X=)	σ^-	$(\sigma)^b$	yield/%
1	4-C≡N	0.66	(1.00)	93
2	4-$COCH_3$	-	(0.87)	92
3	4-CH_3	-0.31	(-0.17)	69
4	4-SCH_3	-0.60	(-0.05)	35
5	4-OCH_3	-0.78	(-0.27)	36

[a]A solution of $NiCl_2$(dppf) (0.03 mmol) and dppf (0.03 mmol) in dioxane (6 ml) was treated with BuLi (0.12 mmol in hexane). A mesylate (1 mmol), *o*-tolylboronic acid (1.3 mmol) and K_3PO_4•nH_2O (2 mmol) were added and the mixture was then stirred at 70 ℃ for 16.
[b]Hammett constant.

The coupling of tolylboronic acid with *p*-methoxyphenyl mesylate was carried out by using various solvents and catalysts to optimize the reaction conditions (Table 2). The reaction in the presence of a reduced nickel(0) catalyst and K_3PO_4•nH_2O in dioxane again did not give good results, though the yield slightly increased when an additional dppf ligand was used (entries 1 and 2). An addition of metal halides exhibits a remarkable accelerating effect in various coupling reactions of aryl triflates,[7] but the presence of LiBr or LiCl was not effective for the mesylates (entry 3). The formation of in small amount *p*-methoxyphenol derived from the saponification of the mesylates was observed on prolongation of the reaction time in dioxane. Thus, the conditions were next optimized in a toluene solution because a solvent which is not miscible with the inorganic base will avoid such saponification (entries 4-14). The effect of a ligand revealed the following order of yields, thus suggesting the effectiveness of bidentate ligands having a large bite angle;[8] dppf > dppp ~ PCy_3 > PPh_3 > dppe (entries 4-9). Higher yields were obtained when the

ratio of P/Ni is 4 (for an example, entries 8 and 9), except the strongly coordinating ligands such as tricyclohexylphosphine (entry 5). The use of excess phosphine, in general, retards the oxidative addition, but an additional ligand can be necessary to stabilize the catalyst because the nickel(0) complexes are a highly reactive, but highly labile species. The reaction was further accelerated at 100 ℃ and the best yield was finally achieved when 3 equivalents of $K_3PO_4 \cdot nH_2O$ was used (entry 11).

The reduction of the nickel chloride complex with BuLi or DIBAH is recommended both to reduce the formation of homo-coupling products of arylboronic acids and to achieve reproducible results. However, slightly lower, but almost comparable yields can be also obtained without the reduction of the nickel(II) catalyst (entry 12). The finely powdered and hydrated phosphate which contains 2~3 moles of water worked efficiently as the base, but the anhydrous phosphate was not effective (entry 13).[9]

Table 2. Reaction Conditions[a]

entry	catalyst	additive (equivs)	solvent	temp/°C	yield/%
1	$NiCl_2$(dppf)	$K_3PO_4 \cdot nH_2O$ (2)	dioxane	80	39
2	$NiCl_2$(dppf)/dppf	$K_3PO_4 \cdot nH_2O$ (2)	dioxane	80	50
3	$NiCl_2$(dppf)/dppf	$K_3PO_4 \cdot nH_2O$ (2)/LiBr (1.1)	dioxane	80	2
4	$NiCl_2(PPh_3)_2$/2PPh_3	$K_3PO_4 \cdot nH_2O$ (2)	toluene	80	30
5	$NiCl_2(PCy_3)_2$	$K_3PO_4 \cdot nH_2O$ (2)	toluene	80	44
6	$NiCl_2$(dppe)/dppe	$K_3PO_4 \cdot nH_2O$ (2)	toluene	80	19
7	$NiCl_2$(dppp)/dppp	$K_3PO_4 \cdot nH_2O$ (2)	toluene	80	43
8	$NiCl_2$(dppf)	$K_3PO_4 \cdot nH_2O$ (2)	toluene	80	50
9	$NiCl_2$(dppf)/dppf	$K_3PO_4 \cdot nH_2O$ (2)	toluene	80	57
10	$NiCl_2$(dppf)/dppf	$K_3PO_4 \cdot nH_2O$ (2)	toluene	100	59
11	$NiCl_2$(dppf)/dppf	$K_3PO_4 \cdot nH_2O$ (3)	toluene	100	85
12	$NiCl_2$(dppf)/dppf[b]	$K_3PO_4 \cdot nH_2O$ (3)	toluene	100	74
13	$NiCl_2$(dppf)/dppf	K_3PO_4 (3)	toluene	100	25

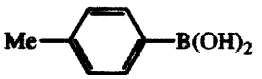
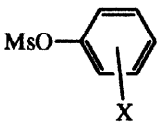
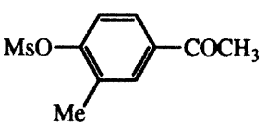
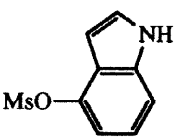
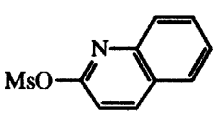
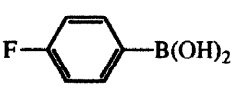
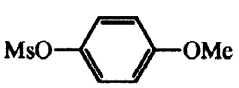
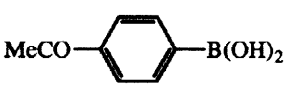
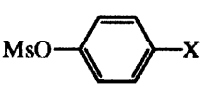
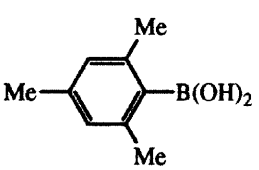
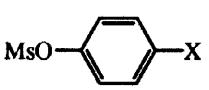
[a]A solution of $NiCl_2 \cdot L_2$ (3 mol%) and additional ligand (L, 3 mol%) was treated with BuLi (4 equivs) at room temperature to give a nickel(0) catalyst. *p*-$MeC_6H_4B(OH)_2$ (1.3 equivs), *p*-$MeOC_6H_4OMs$ (1.0 equivs) and $K_3PO_4 \cdot nH_2O$ (2~3 equivs) were added to the catalyst solution, and the mixture was then stirred for 16 h at the temperature shown in Table.
[b]The nickel chloride complex was directly used without the reduction.

Scope and Limitation

The synthesis of biaryls *via* the cross-coupling reaction of the representative aryl mesylates is summarized in Table 3.

Aryl mesylates having both an electron-withdrawing and -donating group at the *para* and the *meta* position gave excellent yields of biaryls often exceeding 90% (entries 1-10). The electron-withdrawing

Table 3. The Synthesis of Biaryls (Eq. 1)[a]

entry	$ArB(OH)_2$	ArOMs			product No.	yield/%[b]
1			X=	*p*-C≡N	**3a**	97
2				*p*-COMe	**3b**	86
3				*p*-CO_2Me	**3c**	90
4				*m*-CO_2Me	**3d**	76
5				*o*-CO_2Me	**3e**	47
6				*p*-Ph	**3f**	75
7				*p*-CH_2Ph	**3g**	67
8				*p*-$CH_2CH_2COCH_3$	**3h**	90
9				*p*-OMe	**3i**	77 (85)[c]
10				*m*-OMe	**3j**	95
11					**3k**	81
12					**3l**	85
13					**3m**	trace
14					**3n**	62
15				X = CN	**3o**	55 (98)[d]
16				X = OMe	**3p**	27 (34)[d]
17				X = CN	**3q**	56
18				X = OMe	**3r**	53

[a]A mixture of $NiCl_2$(dppf) (0.04 mmol) and dppf (0.04 mmol) in toluene was treated with BuLi (4 equivs) to reduce to the nickel(0) compex. The catalyst solution was added to a mixture of arylboronic acid (1.3 mmol), aryl mesylate (1.0 mmol), and $K_3PO_4 \cdot nH_2O$ (3 mmol) in toluene, and the mixture was stirred at 100 °C for 16 h. The reactions in entries 1-4, 15, and 17 were carried out at 80 °C. [b]Isolated yields by chromatography. [c]GC yields. [d]The reaction was carried out in DME at 80 °C.

group accelerates the rates of oxidative addition and the transmetalation among the three steps involved in the catalytic cycle. The *ortho*-substitution decreased the yield due to its steric hindrance (entry 5), but this was not the case for further electron-deficient mesylate (entry 11). 4-Methanesulfoxyindole underwent smooth coupling without any difficulty (entry 12), but the reaction failed with 2-methanesulfoxyquinoline (entry 13). Arylboronic acids are, in general, stable to water and base, but the presence of an electron-withdrawing group enhances the rate of protodeboronation[10] which often reduces the yield of a cross-coupling reaction of organoboronic acids. Indeed, the reaction of 4-acetylphenylboronic acid suffered from the formation of acetophenone and low coupling yields (entries 15 and 16). However, it was interesting that the coupling was exceptionally faster than the protodeboronation when the reaction was carried out at 80 ℃ in dimethoxyethane (DME) (entry 15). The coupling of mesitylboronic acid often fails because of its large steric hindrance during the transmetalation. Although the nickel-catalyzed reaction is more sensitive to steric hindrance than that catalyzed by palladium,[4] both reactions with electron-rich and -deficient mesylates resulted in moderate yields (entries 17 and 18).

Experimental Section

Reagents. The reaction of $NiCl_2 \cdot 6H_2O$ with a commercially available phosphine in benzene at 50 ℃ gave the nickel chloride complexes with dppf (1,1'-bis(diphenylphosphino)ferrocene), dppe ($Ph_2PCH_2CH_2PPh_2$), dppp ($Ph_2PCH_2CH_2CH_2PPh_2$), tricyclohexylphosphine (PCy_3), and triphenylphosphine.[11] Aryl mesylates were prepared by the reaction of methanesulfonyl chloride with phenol in ether in the presence of triethylamine. 4-Tolylboronic acid, 4-acetylphenylboronic acid, and mesitylboronic acid were commercially available from Lancaster.[12] $K_3PO_4 \cdot nH_2O$ (n = 2~3) from Nakarai Tesque Co. was used directly. Dioxane and toluene were distilled from benzophenone ketyl.

Effect of Substituents (Table 1). The flask was charged with $NiCl_2$(dppf) (0.03 mmol) and dppf (0.03 mmol) and then flushed with argon. The catalyst was dissolved in dioxane (6 mL) and treated with n-BuLi in hexane (0.12 mmol) at room temperature for 10 min to give a solution of the nicked(0) complex. *o*-Tolylboronic acid (1.3 mmol), $K_3PO_4 \cdot nH_2O$ (3 mmol), and aryl mesylate were added to the flask and the mixture was stirred at 70 ℃ for 16 h. The product was extracted with ether, washed with brine, and dried over $MgSO_4$. Chromatography over silica gel gave the corresponding biaryl.

Reaction Conditions (Table 2). The flask charged with $NiCl_2 \cdot L$ (L = dppf, dppe, dppp, and 2 PPh_3, 2 PCy_3) (0.03 mmol or 0.04 mmol) and additional ligand shown in Table 2 (0.03 or 0.04 mmol) was flushed with argon. The catalyst was dissolved in solvent (2 mL) and treated with n-BuLi in hexane (4 equivs) at room temperature for 30 min to give a solution of the nickel(0) complex. *p*-Tolylboronic acid (1.3 mmol), 4-methoxyphenyl mesylate (1.0 mmol), and $K_3PO_4 \cdot nH_2O$ (2 or 3 mmol) were added to the catalyst solution, and the resulting mixture was stirred for 16 h at the temperature shown in Table 2.

Representative Procedure (Table 3). The following procedure for the cross-coupling of *p*-tolylboronic acid with 4-cyanophenyl mesylates is representative (entry 1). A 25 mL-flask charged with

$NiCl_2$(dppf) (0.028 g, 0.04 mmol) and dppf (0.022 g, 0.04 mmol) was flushed with argon. The catalyst was dissolved in toluene (2 mL) and then treated with n-BuLi (1.6 M, 0.1 mL, 0.16 mmol) at room temperature for 30 min to give a solution of nickel(0) complex. Another 25 mL-flask was charged with *p*-tolylboronic acid (0.177 g, 1.3 mmol), $K_3PO_4 \cdot nH_2O$ (0.636 g, 3 mmol), 4-cyanophenyl mesylate (1 mmol), and toluene (2 mL) under argon. The nickel(0) complex solution was added to the flask by using a syringe. After being stirred for 16 h at 80 ℃, the reaction mixture was diluted with benzene, washed with water, and dried over $MgSO_4$. Purification by chromatography over silica gel (hexane/ethyl acetate = 10/1) afforded 0.191 g (97 %) of 4-cyano-4'-methylbiphenyl (**3a**) as a white crystal: IR (Nujol) 2220 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) : δ 2.41 (s, 3H), 7.28 (d, *J*= 8.0 Hz, 2H), 7.49 (d, *J*= 8.0 Hz, 2H), 7.66 (d, *J*= 8.3 Hz, 2H), 7.70 (d, *J*= 8.3 Hz, 2H); MS *m/z* 75 (3), 82 (6), 91 (8), 140 (4), 152 (4), 165 (16), 177 (7), 193 (M^+, 100); exact mass calcd for $C_{14}H_{11}N$ 193.0891, found 193.0888.

The following biaryls were prepared by the above general procedure, unless otherwise noted.

3b: IR (Nujol) 1690 cm^{-1}; ^1H NMR δ 2,41 (s, 3H), 2,64 (s, 3H), 7.28 (d, *J*= 7.9 Hz, 2H), 7.53 (d, *J*= 7.9 Hz, 2H), 7.67 (d, *J*= 8.7 Hz, 2H), 8.02 (d, *J*= 8.7 Hz, 2H); MS *m/z* 76 (4), 82 (7), 98 (8), 115 (5), 128 (2), 139 (4), 152 (31), 165 (22), 195 (100), 210 (M^+, 55); exact mass calcd for $C_{15}H_4O$ 210.1045, found 210.1040.

3c: IR (Nujol) 1730 cm^{-1}; ^1H NMR δ 2.41 (s, 3H), 3.94 (s, 3H), 7.76 (d, *J*= 8.0 Hz, 2H), 7.53 (d, *J*= 8.0 Hz, 2H), 7.65 (d, *J*= 8.6 Hz, 2H), 8.09 (d, *J*= 8.6 Hz, 2H); MS *m/z* 76 (4), 82 (12), 98 (16), 115 (5), 128 (2), 139 (4), 152 (34), 165 (25), 195 (100), 226 (M^+, 90); exact mass calcd for $C_{15}H_{14}O_2$ 226.0994, found 226.0990.

3d: IR (Nujol) 1730 cm^{-1}; ^1H NMR δ 2.41 (s, 3H), 3.94 (s, 3H), 7.27 (d, *J*= 8.9 Hz, 2H), 7.49 (dd, *J*= 7.6 and 7.8 Hz, 1H), 7.52 (d, *J*= 8.9 Hz, 2H), 7.77 (d, *J*= 7.8 Hz, 1H), 7.99 (d, *J*= 7.6 Hz, 1H), 8.27 (s, 1H); MS *m/z* 76 (4), 91 (3), 98 (7), 115 (9), 128 (3), 139 (9), 152 (50), 167 (42), 195 (72), 226 (M^+, 100); exact mass calcd for $C_{15}H_{14}O_2$ 226.0994, found 226.0993.

3e: IR (Nujol) 1720 cm^{-1}; ^1H NMR δ 2.39 (s, 3H), 3.66 (s, 3H), 7.18-7.24 (m, 4H), 7.36 (dd, *J*= 1.4 and 7.6 Hz, 1H), 7.38 (ddd, *J*= 1.4, 7.6 and 7.6 Hz, 1H), 7.51 (ddd, *J*= 1.4, 7.6 and 7.6 Hz, 1H), 7.80 (dd, *J*= 1.4 and 7.8 Hz, 1H); MS *m/z* 76 (5), 98 (3), 115 (9), 128 (4), 139 (10), 152 (47), 167 (26), 195 (100), 226 (M^+, 73); exact mass calcd for $C_{15}H_{14}O_2$ 226.0994, found 226.1003.

3f: ^1H NMR δ 2.41 (s, 3H), 7.27 (d, *J*= 8.1 Hz, 2H), 7.35 (dd, *J*= 7.3 and 7.3 Hz, 1H), 7.46 (dd, *J*= 7.3 and 8.1 Hz, 2H), 7.54 (d, *J*= 8.1 Hz, 2H), 7.63-7.66 (m, 6H); MS *m/z* 77 (4), 91 (10), 115 (7), 122 (10), 152 (6), 165 (15), 202 (6), 215 (5), 228 (9), 244 (M^+, 100); exact mass calcd for $C_{19}H_{16}$ 244.1252, found 244.1249.

3g: ^1H NMR δ 2.38 (s, 3H), 4.01 (s, 2H), 7.22-7.32 (m, 9H), 7.46 (d, *J*= 8.3 Hz, 2H), 7.49 (d, *J*= 8.3 Hz, 2H); MS *m/z* 77 (4), 91 (15), 115 (9), 128 (9), 139 (4), 152 (8), 165 (44), 181 (13), 243 (15), 258 (M^+, 100); exact mass calcd for $C_{20}H_{18}$ 258.1409, found 258.1408.

3h: IR (Nujol) 1710 cm^{-1}; ^1H NMR δ 2.16 (s, 3H), 2.39 (s, 3H), 2.80 (t, *J*= 7.3 Hz, 2H), 2.93 (t, *J*= 7.3 Hz, 2H), 7.23 (d, *J*= 8.1 Hz, 2H), 7.24 (d, *J*= 8.1 Hz, 2H), 7.47 (d, *J*=8.1 Hz, 2H), 7.49 (d, *J*= 8.1 Hz, 2H); MS *m/z* 77 (6), 91 (5), 115 (9), 128 (4), 139 (4), 152 (13), 165 (37), 181 (100), 195 (14), 238 (M^+, 55); exact mass calcd for $C_{15}H_{14}O_2$ 238.1358, found 238.1358.

3i: ^{1}H NMR δ 2.38 (s, 3H), 3.85 (s, 3H), 6.96 (d, *J*= 8.8 Hz, 2H), 7.22 (d, *J*= 8.1 Hz, 2H), 7.45 (d, *J*= 8.1 Hz, 2H), 7.51 (d, *J*= 8.8 Hz, 2H) ; MS *m/z* 76 (4), 82 (2), 99 (9), 115 (5), 128 (6), 139 (4), 155 (24), 165 (3), 183 (51), 198 (M^+, 100); exact mass calcd for $C_{14}H_{14}O$ 198.1045, found 198.1034.

3j: ^{1}H NMR δ 2.39 (s, 3H), 3.86 (s, 3H), 6.87 (dd, *J*= 2.4 and 8.0 Hz, 1H), 7.10 (dd, *J*= 1.7 and 2.4 Hz, 1H), 7.16 (d, *J*= 7.8 Hz, 1H), 7.24 (d, *J*= 7.9 Hz, 2H), 7.34 (dd, *J*= 7.8 and 8.0 Hz, 1H), 7.49 (d, *J*= 7.9 Hz, 2H); MS *m/z* 155 (21), 167 (19), 187 (12), 198 (M^+, 100), 199 (18); exact mass calcd for $C_{14}H_{14}O$ 198.1045, found 198.1049

3k: IR (Nujol) 1674 cm^{-1}; ^{1}H NMR δ 2.34 (s, 3H), 2.42 (s, 3H), 2.62 (s, 3H), 7.20-7.24 (m, 4H), 7.31 (d, *J*= 8.0 Hz, 1H), 7.81 (dd, J= 1.7 and 8.0 Hz, 1H), 7.86 (d, *J*= 1.7 Hz, 1H); MS *m/z* 166 (29), 181 (14), 209 (100), 224 (M^+, 59); exact mass calcd for $C_{16}H_{16}O$ 224.1201, found 224.1206.

3l: ^{1}H NMR δ 2.43 (s, 3H), 6.73 (m, 1H), 7.18 (d, *J*=7.3 Hz, 1H), 7.23 (dd, *J*= 6.1 and 6.8 Hz, 1H), 7.29 (d, *J*=7.9 Hz, 2H), 7.35-7.37 (m, 2H), 7.61 (d, *J*= 7.9 Hz, 2H); MS *m/z* 179 (15), 191 (5), 206 (29), 207 (M^+, 100), 208 (19); exact mass calcd for $C_{15}H_{13}N$ 207.1048, found 207.1054.

3n: ^{1}H NMR δ 3.85 (s, 3H), 6.97 (d, *J*= 8.8 Hz, 2H), 7.10 (dd, *J*= 8.6 and 8.8 Hz, 2H), 7.47 (d, *J*= 8.8 Hz, 2H), 7.49 (dd, *J*= 5.2 and 8.8 Hz, 2H); MS *m/z* 133 (46), 159 (69), 187 (53), 202 (M^+, 100); exact mass calcd for $C_{13}H_{11}OF$ 202.0794, found 202.0792.

3o: The reaction was carried out in DME at 80 ℃ for 16 h. IR (Nujol) 2227, 1685 cm^{-1}; ^{1}H NMR δ 2.66 (s, 3H), 7.68 - 7.78 (m, 6H), 8.07 (d, *J* = 8.3 Hz, 2H); MS *m/z* 151 (28), 178 (33), 206 (100), 221 (M^+, 40); exact mass calcd for $C_{15}H_{11}NO$ 221.0840, found 221.0835.

3p: The reaction was carried out in DME at 80 ℃ for 16 h. IR (Nujol) 1680 cm^{-1}; ^{1}H NMR δ 2.63 (s, 3H), 3.87 (s, 3H), 7.00 (d, *J*= 8.5 Hz, 2H), 7.58 (d, *J*= 8.5 Hz, 2H), 7.65 (d, *J*= 8.3 Hz, 2H), 8.01 (d, *J*= 8.3 Hz, 2H); MS *m/z* 76 (9), 106 (12), 139 (39), 152 (18), 128 (8), 168 (26), 183 (17), 211 (100), 226 (M^+, 68); exact mass calcd for $C_{15}H_{14}O_2$ 226.0994, found 226.0985.

3q: IR (Nujol) 2361 cm^{-1}; ^{1}H NMR δ 0.197 (s, 6H), 2.33 (s, 3H), 6.95 (s, 2H), 7.27 (d, *J*= 7.9 Hz, 2H), 7.72 (d, *J*= 7.9 Hz, 2H); MS *m/z* 179 (12), 190 (25), 206 (73), 221 (M^+, 100); exact mass calcd for $C_{16}H_{15}N$ 221.1205, found 221.1209

3r: ^{1}H NMR δ 2.01 (s, 6H), 2.32 (s, 3H), 3.85 (s, 3H), 6.93 (s, 2H), 6.95 (d, *J*= 8.2 Hz, 2H), 7.05 (d, *J*= 8.2 Hz, 2H); MS *m/z* 77 (6), 112 (4), 128 (6), 141 (6), 153 (12), 165 (15), 183 (12), 195 (16), 211 (31), 226 (M^+, 100); exact mass calcd for $C_{16}H_{18}O$ 226.1358, found 226.1355.

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