Stereospecific Synthesis of 3,3-Disubstituted Acrylonitriles by Heck Reaction

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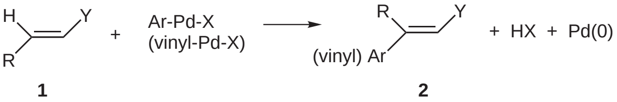
Abstract: The coupling reaction of 3-aryl (or heteroaryl) acrylonitriles with several aryl and heteroaryl iodides (Heck reaction) under Jeffery's conditions has been studied as a concept to synthesize, in a stereospecific manner, trisubstituted olefins.

Key words: arylations, Heck reaction, heterocycles, Palladium catalysis, alkenes

The palladium(0)-catalyzed reaction of aryl and alkenyl halides with alkenes (the Heck reaction) has now become a well-established synthetic method for the formation of carbon–carbon bonds.[1] The Heck reaction gives, in general, excellent results with monosubstituted or 1,1-disubstituted olefins, but only few examples of arylation and alkenylation of 1,2-disubstituted or trisubstituted alkenes have been reported.[2] As the established mechanism of the Heck reaction includes *syn* addition of an organopalladium intermediate (e.g. Ar–Pd–X) to the olefin **1** and *syn* elimination of palladium hydride H–Pd–X, it can afford stereospecifically the final olefin **2** (Scheme 1). An unprecedented case of stereoselectivity was reported by Buchwald et al. in Heck arylations of 1,1- and 1,2-disubstituted olefins, e.g., cinnamates and methacrylates in the presence of bulky amines, that seems to be thermodynamically controled in nature.[2e]



Scheme 1

We have reported in a previous short communication the stereospecific preparation of (*E*)- and (*Z*)-3,3-diarylacrylonitriles by Heck reaction.[2d] We obtained them in highly diastereoselective Pd-catalyzed Heck reactions under Jeffery's conditions between (*E*)-cinnamonitriles and aryl iodides. However, to the best of our knowledge, no other cases of β-arylation of cinnamonitriles by Heck reaction have been reported since then. To widen the scope of this powerful methodology, we decided to investigate the stereospecific preparation of 3,3-disubstituted acrylonitriles involving some heteroaromatic systems such as thiophene, pyridine and ferrocene derivatives. Introduction of ferrocene moieties can be relevant for potential applications of ferrocenylacrylonitriles as electrochemically switchable non-linear optical materials.[3]

In Scheme 2 and in Table 1 we present our results on the Heck reaction in obtaining stereochemically pure 3,3-disubstituted acrylonitriles **9**–**12**. Compounds **9**, **11** and **12** bearing aryl, thienyl and pyridyl groups, respectively, have been prepared non-sterereoselectively from benzophenones either by aldol or Wittig-type reactions.[4] 3,3-Disubstituted acrylonitriles containing ferrocene units, **10**, have been prepared by condensation of ferrocenyliminium salts and cyanoacetate esters, followed by saponification and decarboxylation to give equal amounts of the isomeric cyano olefins.[5]

The reaction of (*E*)-cinnamonitrile (**3e**) with several *para*-substituted aryl iodides **7a**–**h** gives (*E*)-3,3-diarylacrylonitriles **9a**–**h** with high stereoselectivity. After some optimization, a procedure employing $Pd(OAc)_2$/KOAc/*n*-Bu_4NBr in DMF (Jeffery's conditions)[6] was very effective in coupling cinnamonitriles with both electron-rich and electron-poor aryl iodide substrates. In most cases *Z* isomers could not be detected (entries 1–6, 8). For aryl iodides with electron-withdrawing substituents (Entries 6–8), longer reaction times and higher temperatures were required. In order to obtain the *Z* isomers, cinnamonitriles **3a**–**d**,**f**,**h** were made to react with iodobenzene **7e** under the already defined Jeffery's conditions. In all cases the reactions were completely stereoselective (entries 9–14). The stereochemistry of (*E*)-**9b** and (*Z*)-**9h** were corroborated by NOE experiments, all other 3,3-diarylacrylonitriles **9** are supposed to belong to the same stereochemical families.

These results prompted us to investigate the arylation of 3-heteroarylacrylonitriles such as (*E*)-3-ferrocenylacrylonitrile [(*E*)-**4**], (*E*)-3-(2-thienyl)acrylonitrile (**5**) and (*E*)-3-(3-pyridyl)acrylonitrile (**6**) with electron-rich aryl iodides in order to broaden the scope of the reaction. A high activity has been observed for ferrocenylacrylonitrile (*E*)-**4**, requiring lower reaction times than for the corresponding cinnamonitriles **3** to give (*Z*)-**10b**–**e**. In contrast, *E* isomers were also formed in these cases, although in low yields (entries 15–18).

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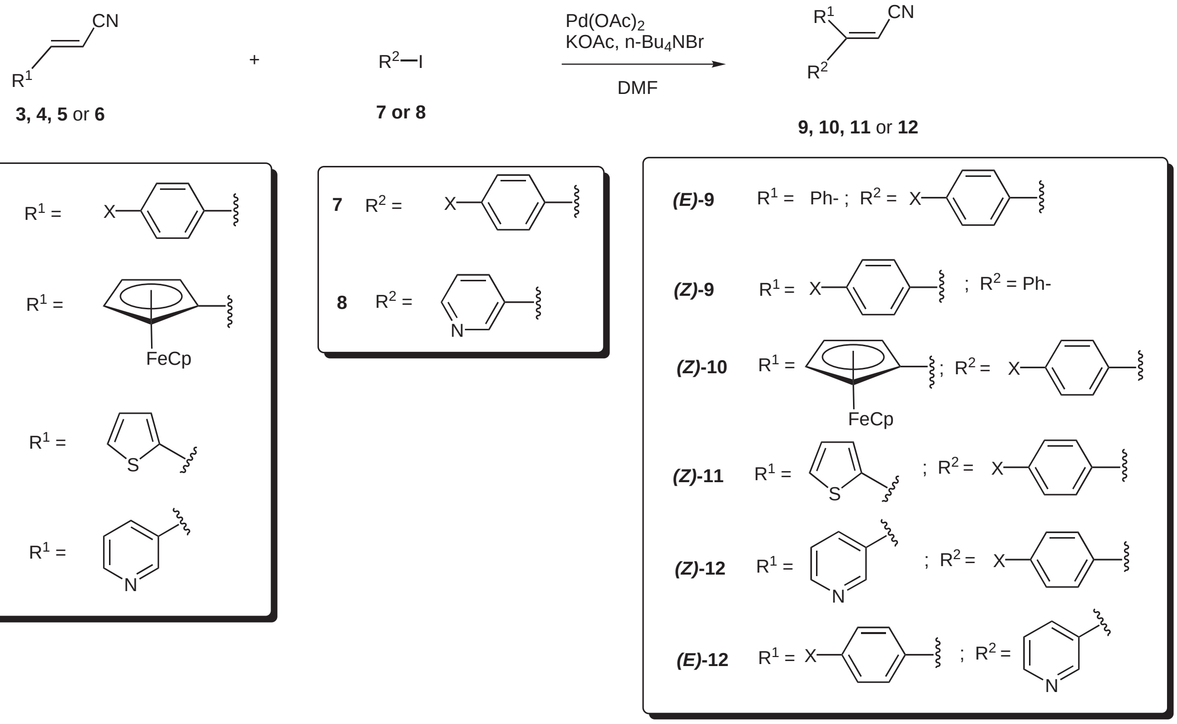


Scheme 2

Table 1 Palladium(0)-Catalyzed Arylation of 3-Substituted Acrylonitriles **3**–**6**

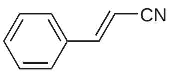
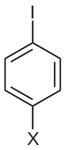
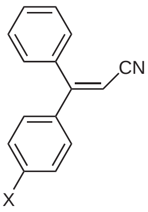
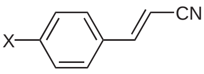
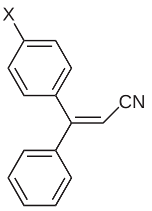
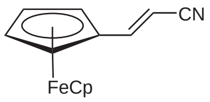
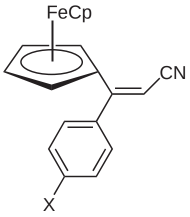
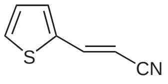
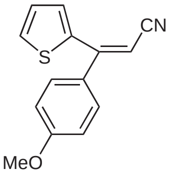
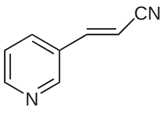
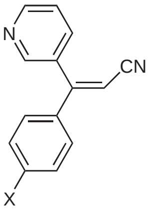
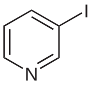
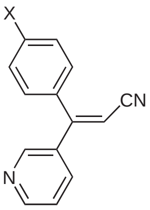
Entry	Olefin	Arene	Product	Ratio E/Z[a]	T (°C)/t (days)	Yield (%)[b,c]
1	 **3e**	 **7a** (X = NH_2)	 (E)-**9a** (X = NH_2)	100:0	80/2	78
2	**3e**	**7b** (X = MeO)	(E)-**9b** (X = OMe)	100:0	80/1	84
3	**3e**	**7c** (X = AcNH)	(E)-**9c** (X = AcNH)	100:0	80/3	86
4	**3e**	**7d** (X = Me)	(E)-**9d** (X = Me)	100:0	80/2	80 (91)
5	**3e**	**7e** (X = H)	**9e** (X = H)	–	80/3	74 (88)
6	**3e**	**7f** (X = Cl)	(E)-**9f** (X = Cl)	100:0	100/2 + 120/8	73 (81)[d]
7	**3e**	**7g** (X = MeCO)	(E)-**9g** (X = MeCO)	96:4	80/2 + 100/6	28 (51)[e]
8	**3e**	**7h** (X = CF_3)	(E)-**9h** (X = CF_3)	100:0	100/6 + 120/2	28 (58)[e]
9	 **3a** (X = NH_2)	7**e**	 (Z)-**9a** (X = NH_2)	0:100	80/3	60 (79)
10	**3b** (X = MeO)	**7e**	(Z)-**9b** (X = MeO)	0:100	80/3	76

Table 1 Palladium(0)-Catalyzed Arylation of 3-Substituted Acrylonitriles **3**–**6** (continued)

Entry	Olefin	Arene	Product	Ratio *E*/*Z*[a]	T (°C)/t (days)	Yield (%)[b,c]
11	**3c** (X = AcNH)	**7e**	(*Z*)-**9c** (X = AcNH)	0:100	80/3	73 (88)
12	**3d** (X = Me)	**7e**	(*Z*)-**9d** (X = Me)	0:100	80/4	75 (87)
13	**3f** (X = Cl)	**7e**	(*Z*)-**9f** (X = Cl)	0:100	80/3	80
14	**3h** (X = CF_3)	**7e**	(*Z*)-**9h** (X = CF_3)	0:100	80/2	74 (86)
15	 (*E*)-**4**	**7b**	 (*Z*)-**10b** (X = OMe)	16:84	80/1	89
16	(*E*)-**4**	**7c**	(*Z*)-**10c** (X = AcNH)	10:90	80/2	73 (78)
17	(*E*)-**4**	**7d**	(*Z*)-**10d** (X = Me)	3:97	80/1	64
18	(*E*)-**4**	**7e**	(*Z*)-**10e** (X = H)	7:93	80/2	63 (71)
19	(*Z*)-**4**	**7b**	(*E*)-**10b** (X = OMe)	100:0	100/3	28 (36)[f]
20	(*Z*)-**4**	**7c**	(*E*)-**10c** (X = AcNH)	100:0	100/4	24 (31)[f]
21	 **5**	**7b**	 (*Z*)-**11b** (X = OMe)	7:93	80/6 hours	48 (56)[g]
22	 **6**	**7a**	 (*Z*)-**12a** (X = NH_2)	5:95	80/3	55 (66)
23	**6**	**7b**	(*Z*)-**12b** (X = OMe)	14:86	80/3	67 (76)
24	**6**	**7d**	(*Z*)-**12d** (X = Me)	7:93	80/4	74 (86)
25	**3e**	 **8**	 (*E*)-**12e** (X = H)	92:8	120/2	42 (93)
26	**3d**	**8**	(*E*)-**12d** (X = Me)	100:0	120/2	45 (93)

[a] Ratio *E*/*Z* calculated by ^1H NMR integration.

[b] Yields of pure isolated products. When mixtures of *Z*/*E* isomers were obtained, the combined yield is given.

[c] In parentheses yields with respect to non-recovered starting material.

[d] Reaction carried out in the presence of 20% molar of tri-*o*-tolylphosphine.

[e] *n*-Bu_4NCl and $NaHCO_3$ were used instead of *n*-Bu_4NBr and KOAc.

[f] 5–9% of regioisomers formed by arylation in the α-position of (*Z*)-**4** were obtained.

[g] By products arising from arylation of thiophene ring were formed.

Attempted preparation of (*E*)-3-aryl-3-ferrocenylacrylonitriles by reaction of *para*-substituted cinnamonitriles **3** with iodoferrocene failed. Several reaction conditions were tried [$Pd(OAc)_2$, KOAc, *n*-Bu_4NBr, DMF, 100 °C; $Pd(PPh_3)_4$, KOAc, MeCN, 80 °C; $Pd(OAc)_2$, CuI, Et_3N, MeCN, reflux; $Pd(OAc)_2$, Ph_3P, Et_3N, MeCN, 100 °C; $Pd(OAc)_2$, Cy_2NMe, *n*-Bu_4NBr, DMF, 120 °C; $Pd_2(dba)_3$, tri-2-furylphosphine (TFP), Cy_2NMe, toluene, 100 °C] but unfortunately recovered starting materials or decomposition products were obtained. Since the Heck reaction of acrylonitrile with iodoferrocene has been reported,[7] we prepared 3-ferrocenylacrylonitrile (**4**) by coupling acrylonitrile with iodoferrocene using Jeffery's conditions. We obtained compound **4** in 89% yield as a mixture of *E* and *Z* isomers (81:19). An alternative method to prepare ferrocene-containing (*E*)**-10** isomers would be the reaction between (*Z*)-3-ferrocenylacrylonitrile [(*Z*)**-4**], with aryl iodides (Entries 19 and 20). In the case of aryl iodides **7b**,**c**, we could isolate the corresponding *E* isomer, (*E*)-**10b**,**c**, but only in 28 and 24% yield, respectively. In both cases, no traces of the (*Z*)-isomer could be detected, but 5–9% of regioisomers formed by arylation in the α-position of ferrocenylacrylonitrile (*Z*)**-4** could be isolated.

We next turn our attention to the reactions of thienylacrylonitrile (**5**) and pyridylacrylonitrile (**6**) with several aryl iodides. The optimized Jeffery's conditions also effects the Heck coupling of olefins **5** and **6** to generate trisubstituted acrylonitriles (*Z*)**-11** and (*Z*)**-12**, respectively, in good yields and with excellent *Z*/*E* stereoselectivity (Entries 21–24).

The stereochemistry of all new compounds [(*Z*)**-10b**,**d,** (*Z*)**-11b,** (*Z*)**-12a**,**b**,**d**] was secured by NOE experiments.

In order to obtain the *E* isomers of thienyl and pyridyl derivatives, 2-iodothiophene and 3-iodopyridine (**8**) were treated with several cinnamonitriles **3** under the usual conditions. The reaction with 2-iodothiophene did not afford the corresponding trisubstituted olefin. Apart from our optimized Jeffery's conditions, several other catalytic systems were tried [$Pd(OAc)_2$, *n*-Bu_4NBr, Cy_2NMe, DMF, 110 °C; $Pd_2(dba)_3$, TFP, Cy_2NMe, toluene, 100 °C; $Pd_2(dba)_3$, TFP, Et_3N, THF, 60 °C; $Pd(OAc)_2$, Ph_3P, Ag_2CO_3, DMF, 80 °C] but all of them failed. In most cases, we could observe that 2-iodothiophene was consumed in the reaction process, leaving some deep red residue, possibly polymeric material from 2-iodothiophene homocoupling as has been reported[8] under the same Jeffery's conditions. On the other hand, acrylonitrile reacts with 2-iodothiophene under Jeffery's conditions to give **5** in quantitative yield and with *E*/*Z* ratio = 75:25. Thereby, we can conclude that the arylation of cinnamonitriles using different catalytic systems has some limitations with iodoferrocene and 2-iodothiophene as the arene substrates.

In contrast, 3-iodopyridine (**8**) was coupled with cinnamonitriles **3e**,**d** to give trisubstituted olefins in moderate yields (Entries 25–26). Higher temperature than in the other cases was required still giving high stereoselectivity. The stereochemistry of (*E*)**-12e** and (*E*)**-12d** was established by NOE experiments on pure isomers.

In summary, we have found a versatile Heck reaction that provides a highly stereoselective route to trisubstituted olefins through reactions of aryl and heteroaryl iodides with 3-monosubstituted acrylonitriles, containing aryl, heteroaryl, and ferrocenyl units.

^{1}H NMR (^{13}C NMR) and NOE spectra were recorded at 250 MHz (62.5 MHz) or at 200 MHz (50 MHz) using Me_4Si as internal standard. Chemical shifts are given in δ units. EI mass spectra were recorded at 70eV. ESI mass spectra were acquired using a Navigator quadrupole instrument; the instrument was operated in the positive ion mode (ES+) at a probe tip voltage of 3 kV. HRMS was obtained at 'S.C.A.I. Unidad de Espectrometría de Masas de la Universidad de Córdoba'. Elemental analysis were determined at 'Servei d'Anàlisi Química de la Universitat Autònoma de Barcelona' and at 'Servei d'Anàlisi de la Universitat de Girona'.

Cinnamonitrile (**3e**), *para*-substituted phenyl iodides **7a**–**b** and **7d**–**h**, and 3-iodopyridine (**8**) are commercially available. 4-Acetamidophenyl iodide (**7c**) [mp 175–176 °C (lit[9] mp 184.5 °C)] was prepared by heating **7a** at 80 °C with Ac_2O for 35 min. (*E*)-*para*-Substituted cinnamonitriles **3a**–**d**,**f**,**h**, (*E*)-3-ferrocenylacrylonitrile [(*E*)-**4**], (*E*)-3-(2-thienyl)acrylonitrile (**5**) and (*E*)-3-(3-pyridyl)acrylonitrile (**6**) were prepared by KOH-catalyzed condensation of MeCN with aldehydes according to a reported procedure.[10] Pure *E* isomers were isolated by recrystallization [(*E*)-**3**, (*E*)-**4** and **6**] or by flash chromatography (**5**). Compounds **3a**,**c** were obtained in the same reaction from 4-acetylaminobenzaldehyde, partial hydrolysis affording **3c**. Physical constants of these α,β-unsaturated nitriles are specified below.

3a

Mp 109–111 °C (lit.[11] mp 109–110 °C).

3b

Mp 62–63 °C (lit.[10] mp 62–63 °C).

3c

Mp 200–202 °C

3d

Mp 70–71 °C (lit.[10] mp 71–72 °C)

3f

Mp 84–86 °C (lit.[10] mp 84–86 °C).

3h

Mp 98–99 °C (lit.[12] mp 97.5-98.5 °C).

(*E*)-4

Mp 91–92 °C (lit.[13] mp 92–93 °C)

5

Colorless oil.[14]

IR (neat): 2213, 1603 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 5.65$ (d, $J = 17.3$ Hz, 1 H), 7.08 (m, 1 H), 7.24 (m, 1 H), 7.41 (m, 1 H), 7.47 (d, $J = 17.3$ Hz, 1 H).

MS: *m*/*z* (%) = 135 (M^+, 100), 108 (60).

6

Mp 105–106 °C (lit.[10] mp 106–107 °C).

Iodoferrocene was prepared according to a reported procedure.[15] All palladium-catalyzed reactions were carried out under nitrogen atmosphere.

(*E*)-3-(4-Methoxyphenyl)-3-phenyl-2-propenenitrile [(*E*)-9b]; General Procedure

Cinnamonitrile (**3e**) (0.28 mL, 0.29 g, 2.24 mmol) was added under nitrogen atmosphere and at r.t. to a mixture of 4-methoxyphenyl iodide (**7b**) (1.00 g, 4.27 mmol), KOAc (0.55 g, 5.60 mmol), tetrabutylammonium bromide (0.79 g, 2.45 mmol), $Pd(OAc)_2$ (25 mg, 0.11 mmol), and DMF (8 mL). The mixture was heated at 80 °C under magnetic stirring for 1 day (GC monitoring), and cooled at r.t. Then H_2O (75 mL) was added and the mixture partitioned with Et_2O (3 × 60 mL). The organic layer was sequentially washed with brine (2 × 100 mL) and with H_2O (100 mL), dried (Na_2SO_4), filtered and the solvent was removed under reduced pressure. The residue was chromatographed (silica gel; *n*-hexane–EtOAc, 95:5) to afford (*E*)-**9b**.

Yield: 0.44 g (84%); colorless solid; mp 70–71 °C.

IR (KBr): 2934, 2215, 1602, 1587, 1512, 1354, 1253, 1185, 1030, 817 cm^{-1}

^1H NMR (250 MHz, $CDCl_3$): δ = 3.84 (s, 3 H), 5.67 (s, 1 H), 6.87 (AA′ part of the AA′BB′ system, 2 H, *J* = 8.8 Hz,), 7.24 (BB′ part of the AA´BB′ system, 2 H, *J* = 8.8 Hz), 7.42–7.46 (m, 5 H).

^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 55.3, 92.7, 114.0, 118.2, 128.4, 129.5, 129.8, 129.9, 131.0, 137.2, 161.5, 162.5.

MS: *m*/*z* (%) = 235 (M^+, 100), 220 (14), 204 (12), 195 (13), 165 (16).

Anal. Calcd for $C_{16}H_{13}NO$: C, 81.68; H, 5.57; N, 5.95. Found: C, 81.46; H, 5.59; N, 5.81.

The following compounds were prepared and isolated according to the general procedure. The reaction time and the temperature for every case are specified in the Table.

(*E*)-3-(4-Aminophenyl)-3-phenyl-2-propenenitrile [(*E*)-9a]

After purification by flash chromatography (*n*-hexane–EtOAc, 70:30), (*E*)-**9a** was obtained.

Yield: 78%; pale yellow solid; mp 138–140 °C.

IR (KBr): 3449, 3360, 2201, 1627, 1604, 1580, 1559, 1513, 1254 cm^{-1}.

^1H NMR (250 MHz, $CDCl_3$): δ = 3.93 (br s, 2 H), 5.60 (s, 1 H), 6.60 (AA′ part of the AA′BB′ system, 2 H, *J* = 8.8 Hz), 7.10 (BB′ part of the AA′BB′ system, 2 H, *J* = 8.8 Hz), 7.40 (m, 5 H).

^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 90.6, 114.3, 118.7, 128.0, 128.3, 129.4, 129.5, 129.8, 137.5, 148.9, 162.9.

MS: *m*/*z* (%) = 220 (M^+, 100), 205 (11), 180 (31).

Anal. Calcd for $C_{15}H_{12}N_2$: C, 81.79; H, 5.49; N, 12.72. Found: C, 81.36; H, 5.75; N, 12.66.

(*E*)-4-(2′-Cyano-1′-phenylvinyl)acetanilide [(*E*)-9c]

After purification by flash chromatography (*n*-hexane–EtOAc, 50:50), (*E*)-**9c** was obtained.

Yield: 86%; colorless solid; mp 182–184 °C.

IR (KBr): 3337, 3054, 2209, 1693, 1571, 1526, 1411, 1263, 821 cm^{-1}.

^1H NMR (250 MHz, $CDCl_3$): δ = 2.20 (s, 3 H), 5.71 (s, 1 H), 7.25–7.45 (m, 10 H).

^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 24.5, 93.5, 118.1, 119.4, 128.5, 129.2, 129.5, 129.9, 134.0, 136.9, 140.3, 162.6, 168.8.

MS *m*/*z* (%) = 262 (M^+, 56), 220 (100), 205 (7), 180 (20).

Anal. Calcd for $C_{17}H_{14}N_2O$: C, 77.84; H, 5.38; N, 10.68. Found: C, 77.54; H, 5.42; N, 10.57.

(*E*)-3-(4-Methylphenyl)-3-phenyl-2-propenenitrile [(*E*)-9d]

After purification by flash chromatography (*n*-hexane–EtOAc, 95:5), (*E*)-**9d** was obtained with traces of cinnamonitrile **3e**. The yield was calculated by ^1H NMR integration. A pure sample of (*E*)-**9d** was isolated by recrystallization from *n*-pentane.

Yield: 80%, 91% with respect to non-recovered cinnamonitrile; colorless solid; mp 74–75 °C.

IR (KBr): 3056, 2214, 1587, 1568, 1443, 1348, 809, 777, 723, 701 cm^{-1}.

^1H NMR (250 MHz, $CDCl_3$): δ = 2.36 (s, 3 H), 5.69 (s, 1 H), 7.16 (br s, 4 H), 7.41 (m, 5 H).

^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 21.2, 93.8, 117.9, 128.3, 128.4, 129.3, 129.4, 129.8, 135.9, 137.1, 140.8, 162.9.

MS: *m*/*z* (%) = 219 (M^+, 100), 204 (83), 179 (22), 108 (11).

Anal. Calcd for $C_{16}H_{13}N$: C, 87.64; H, 5.97; N, 6.39. Found: C, 87.40; H, 5.87; N, 6.25.

3,3-Diphenyl-2-propenenitrile (9e)

After purification by flash chromatography (*n*-hexane–EtOAc, 95:5), **9e** was obtained with traces of cinnamonitrile **3e**. Yield was calculated by ^1H NMR integration. A pure sample of **9e** was isolated by distillation.

Yield: 74%, 88% with respect to non-recovered cinnamonitrile; colorless oil; bp 190–200 °C (bulb-to-bulb distillation)/0.1 mmHg (lit.[10] bp 128–131 °C/0.2 mmHg).

IR (neat): 3059, 2214, 1592, 1569, 1445 cm^{-1}.

^1H NMR (250 MHz, $CDCl_3$): δ = 5.74 (s, 1 H), 7.26–7.50 (m, 10 H).

^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 94.8, 117.8, 128.3, 128.4, 128.5, 129.4, 129.9, 130.3, 136.9, 138.8, 163.0.

MS: *m*/*z* (%) = 205 (M^+, 100), 204 (70), 190 (22), 178 (27), 165 (40), 88 (18), 76 (15).

(*E*)-3-(4-Chlorophenyl)-3-phenyl-2-propenenitrile [(*E*)-9f]

After purification by flash chromatography (*n*-hexane–Et_2O, 90:10), (*E*)-**9f** was obtained with traces of cinnamonitrile **3e**. Yield was calculated by ^1H NMR integration. A pure sample of (*E*)-**9f** was isolated by distillation.

Yield: 73%, 81% with respect to non-recovered cinnamonitrile; colorless oil; bp 230–235 °C (bulb-to-bulb distillation)/0.1mmHg.

IR (neat): 3057, 2214, 1590, 1488, 1093, 1079, 807 cm^{-1}.

^1H NMR (250 MHz, $CDCl_3$): δ = 5.72 (s, 1 H), 7.22 (AA′ part of the AA′BB′ system, 2 H, *J* = 8.7 Hz), 7.34 (BB′ part of the AA′BB′ system, 2 H, *J* = 8.7 Hz), 7.37–7.44 (m, 5 H).

^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 95.3, 117.6, 128.7, 129.0, 129.5, 129.7, 130.3, 136.6, 136.7, 137.4, 161.8.

MS: *m*/*z* (%) = 239 (M^+, 67), 204 (100), 177 (23), 102 (15), 88 (42).

Anal. Calcd for $C_{15}H_{10}ClN$: C, 75.16; H, 4.20; N, 5.84. Found: C, 75.00; H, 3.99; N, 5.68.

(*E*)-3-(4-Acetylphenyl)-3-phenyl-2-propenenitrile [(*E*)-9g]

After purification by flash chromatography (*n*-hexane–EtOAc, 85:15), (*E*)-**9g** was obtained.

Yield: 28%, 51% from non-recovered cinnamonitrile; colorless solid; mp 91–93 °C.

IR (KBr): 3054, 2926, 2213, 1683, 1601, 1267, 826, 713 cm^{-1}.

^{1}H NMR (250 MHz, $CDCl_3$): δ = 2.63 (s, 3 H), 5.81 (s, 1 H), 7.37–7.50 (m, 7 H), 7.96 (BB′ part of the AA′BB′system, 2 H, *J* = 8.75 Hz).

^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 26.7, 96.6, 117.3, 128.5, 128.7, 129.4, 130.3, 136.4, 138.2, 143.2, 161.8, 197.2.

MS: *m*/*z* (%) = 247 (M^+, 43), 232 (100), 203 (21), 177 (18), 88 (15).

Anal. Calcd for $C_{17}H_{13}NO$: C, 82.57; H, 5.30; N, 5.66. Found: C, 82.66; H, 5.46; N, 5.49.

(*E*)-3-[4-(Trifluoromethyl)phenyl]-3-phenyl-2-propenenitrile [(*E*)-9h]

After purification by flash chromatography (*n*-hexane–CH_2Cl_2, 60:40), (*E*)-**9h** was obtained together with recovered cinnamonitrile **3e**. Yield was calculated by ^{1}H NMR integration. A pure sample of (*E*)-**9h** was isolated by recrystallization from *n*-pentane.

Yield: 28%, 58% from non-recovered cinnamonitrile; colorless solid; mp 82–84 °C.

IR (KBr): 3052, 2220, 1413, 1325, 1173, 1118, 1067 cm^{-1}.

^{1}H NMR (250 MHz, $CDCl_3$): δ = 5.78 (s, 1 H), 7.40–7.50 (m, 5 H), 7.43 (AA′ part of the AA′BB′ system, 2 H, *J* = 8.5 Hz), 7.65 (BB′ part of the AA′BB′ system, 2 H, *J* = 8.5 Hz). ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 96.8, 117.2, 123.7 (q, *J* = 270 Hz), 125.6 (q, *J* = 3.7 Hz), 128.7, 128.8, 129.4, 130.4, 132.0 (q, *J* = 33 Hz), 136.3, 142.4, 161.5.

MS: *m*/*z* (%) = 273 (M^+, 100), 233 (31), 204 (70), 177 (14).

Anal. Calcd for $C_{16}H_{10}F_3N$: C, 70.33; H, 3.69; N, 5.12. Found: C, 70.02; H, 3.67; N, 5.13.

(*Z*)-3-(4-Aminophenyl)-3-phenyl-2-propenenitrile [(*Z*)-9a]

After purification by flash chromatography (*n*-hexane–EtOAc, 70:30), (*Z*)-**9a** was obtained.

Yield: 60%, 79% with respect to non-recovered starting compound **3a**; pale yellow solid; mp 103–105 °C.

IR (KBr): 3463, 3360, 3340, 3219, 2205, 1632, 1602, 1516, 1356, 834, 762 cm^{-1}.

^{1}H NMR (250 MHz, $CDCl_3$): δ = 1.62 (br s, 2 H), 5.48 (s, 1 H), 6.69 (AA′ part of the AA′BB′ system, 2 H, *J* = 8.77 Hz), 7.26–7.46 (m, 7 H).

^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 91.8, 114.3, 118.8, 126.7, 128.4, 128.8, 130.0, 131.4, 139.9, 148.4, 163.1.

MS: *m*/*z* (%) = 220 (M^+, 100), 219 (33), 205 (11), 180 (31), 165 (7), 96 (13).

Anal. Calcd for $C_{15}H_{12}N_2$: C, 81.79; H, 5.49; N, 12.72. Found: C, 81.57; H, 5.59; N, 12.55.

(*Z*)-3-(4-Methoxyphenyl)-3-phenyl-2-propenenitrile [(*Z*)-9b]

After purification by flash chromatography (*n*-hexane–EtOAc, 90:10), (*Z*)-**9b** was obtained.

Yield: 76%; colorless oil; bp 240–245 °C (bulb-to-bulb distillation)/0.1 mmHg.

IR (neat): 3057, 2931, 2839, 2211, 1605, 1512, 1254, 1179, 762 cm^{-1}.

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.87 (s, 3 H), 5.60 (s, 1 H), 6.96 (AA′ part of the AA′BB′ system, 2 H, *J* = 8.77 Hz), 7.30–7.45 (m, 5 H), 7.41 (BB′ part of the AA′BB′ system, 2 H, *J* = 8.77 Hz).

^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 55.3, 93.4, 113.8, 118.3, 128.5, 128.6, 129.3, 130.2, 131.3, 139.4, 161.0, 162.7.

MS: *m*/*z* (%) = 235 (M^+, 100), 220 (15), 204 (12), 195 (14), 165 (16).

Anal. Calcd for $C_{16}H_{13}NO$: C, 81.68; H, 5.57; N, 5.95. Found: C, 81.73; H, 5.55; N, 5.76.

(*Z*)-4-(2′-Cyano-1′-phenylvinyl)acetanilide [(*Z*)-9c]

After purification by flash chromatography (*n*-hexane–EtOAc, 70:30), (*Z*)-**9c** was obtained.

Yield: 73%, 88% from non-recovered starting compound **3c**; colorless solid; mp 153–155 °C.

IR (KBr): 3318, 3052, 2212, 1693, 1672, 1598, 1526, 1316 cm^{-1}

^{1}H NMR (250 MHz, $CDCl_3$): δ = 2.21 (s, 3 H), 5.67 (s, 1 H), 7.27–7.45 (m, 8 H), 7.59 (BB′ part of the AA′BB′ system, 2 H, *J* = 8.8 Hz).

^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 24.3, 93.5, 118.3, 119.3, 128.5, 130.3, 132.1, 138.8, 140.1, 163.1, 169.2.

MS: *m*/*z* (%) = 262 (M^+, 50), 220 (100), 219 (25), 180 (25), 43 (48).

Anal. Calcd for $C_{17}H_{14}N_2O$: C, 77.84; H, 5.38; N, 10.68. Found: C, 77.63; H, 5.26; N, 10.38.

(*Z*)-3-(4-Methylphenyl)-3-phenyl-2-propenenitrile [(*Z*)-9d]

After purification by flash chromatography (*n*-hexane–EtOAc, 98:2), (*Z*)-**9d** was obtained.

Yield: 75%, 87% with respect to non-recovered starting compound **3d**; colorless solid; mp 73–75 °C.

IR (KBr): 3030, 2210, 1592, 1445, 822, 766, 695 cm^{-1}.

^{1}H NMR (250 MHz, $CDCl_3$): δ = 2.41 (s, 3 H), 5.68 (s, 1 H), 7.23–7.40 (m, 9 H).

^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 21.3, 94.2, 118.1, 128.5, 128.6, 129.2, 129.5, 130.3, 134.1, 139.2, 140.3, 163.2.

MS: *m*/*z* (%) = 219 (M^+, 100), 204 (75), 179 (20), 108 (10).

Anal. Calcd for $C_{16}H_{13}N$: C, 87.64; H, 5.97; N, 6.39. Found: C, 87.34; H, 5.62; N, 6.34.

(*Z*)-3-(4-Chlorophenyl)-3-phenyl-2-propenenitrile [(*Z*)-9f]

After purification by flash chromatography (*n*-hexane–EtOAc, 95:5), (*Z*)-**9f** was obtained.

Yield: 80%; colorless solid; mp 84–86 °C.

IR (KBr): 3044, 2210, 1571, 1491, 1347, 1087, 830, 759 cm^{-1}.

^{1}H NMR (250 MHz, $CDCl_3$): δ = 5.74 (s, 1 H), 7.26–7.49 (m, 9 H).

^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 95.2, 117.5, 128.3, 128.7, 128.8, 130.6, 130.9, 135.4, 136.1, 138.4, 161.8.

MS: *m*/*z* (%) = 239 (M^+, 72), 204 (100), 203 (37), 177 (23), 88 (34).

Anal. Calcd for $C_{15}H_{10}ClN$: C, 75.16; H, 4.20; N, 5.84. Found: C, 75.41; H, 4.05; N, 5.80.

(*Z*)-3-[4-(Trifluoromethyl)phenyl]-3-phenyl-2-propenenitrile [(*Z*)-9h]

After purification by flash chromatography (*n*-hexane–CH_2Cl_2, 80:20), (*Z*)-**9h** was obtained.

Yield: 74%, 86% from non-recovered starting compound **3h**; colorless solid; mp 105–106 °C.

IR (KBr): 3050, 2211, 1325, 1137, 1115, 1068, 850, 765 cm^{-1}.

^{1}H NMR (250 MHz, $CDCl_3$): δ = 5.85 (s, 1 H), 7.27–7.48 (m, 5 H), 7.55 (AA′ part of the AA′BB′ system, 2 H, *J* = 8.05 Hz), 7.73 (BB′ part of the AA′BB′ system, 2 H, *J* = 8.05 Hz).

^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 96.1, 117.2, 123.6 (q, *J* = 270 Hz), 125.5 (q, *J* = 3.5 Hz), 128.2, 128.8, 129.8, 130.7, 131.6 (q, *J* = 32.9 Hz), 137.8, 140.5, 161.5.

MS: *m*/*z* (%) = 273 (M^+, 100), 233 (30), 204 (69), 177 (12).

Anal. Calcd for $C_{16}H_{10}F_3N$: C, 70.33; H, 3.69; N, 5.13. Found: C, 70.15; H, 3.63; N, 5.14.

(*Z*)-[2-Cyano-1-(4-methoxyphenyl)ethenyl]ferrocene [(*Z*)-10b]

After purification by flash chromatography (*n*-hexane–EtOAc, 95:5), (*Z*)-**10b** was obtained.

Yield: 75%; orange solid; mp 105–106 °C (Et_2O).

IR (KBr): 2928, 2196, 1604, 1509, 1249, 825 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 3.89 (s, 3 H), 4.26 (s, 5 H), 4.51 (apparent t, 2 H, *J* = 1.9 Hz), 4.88 (apparent t, 2 H, *J* = 1.9 Hz), 5.29 (s, 1 H), 6.95 (m, 2 H), 7.35 (m, 2 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 55.4, 70.4, 70.8, 79.0, 89.5, 113.5, 119.5, 129.4, 132.8, 160.5, 163.7.

MS: *m*/*z* (%) = 343 (M^+, 98), 278 (100), 152 (58), 121 (47), 56 (39).

Anal. Calcd for $C_{20}H_{17}ONFe$: C, 69.99; H, 4.99; N, 4.08. Found: C, 69.73; H, 4.82; N, 4.08.

(*E*)-[2-Cyano-1-(4-methoxyphenyl)ethenyl]ferrocene [(*E*)-10b]

By increasing the polarity to *n*-hexane–EtOAc (90:10) in the above, (*E*)-**10b** was obtained.

Yield: 14%; orange solid; mp 104–105 °C (*n*-hexane–Et_2O).

IR (KBr): 2926, 2205, 1606, 1511, 1250 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 3.87 (s, 3 H), 4.15 (s, 5 H), 4.39 (apparent t, 2 H, *J* = 1.9 Hz), 4.45 (apparent t, 2 H, *J* = 1.9 Hz), 5.64 (s, 1 H), 6.99 (AA′ part of the AA′BB′ system, 2 H, *J* = 8.7 Hz), 7.46 (BB′ part of the AA′BB′ system, 2 H, *J* = 8.7 Hz).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 55.3, 68.8, 70.2, 71.2, 81.3, 90.0, 113.7, 118.9, 129.3, 129.9, 160.4, 164.5.

MS: *m*/*z* (%) = 343 (M^+, 100), 278 (98), 152 (53), 121 (45), 56 (47).

HRMS: *m*/*z* calcd. for $C_{20}H_{17}ONFe$: 343.0659; found: 343.0649.

(*Z*)-[2-Cyano-1-(4-acetylaminophenyl)ethenyl]ferrocene [(*Z*)-10c]

After purification by flash chromatography (mixtures of *n*-hexane–EtOAc of increasing polarity from 80:20 to 1:1), **10c** was obtained as a mixture of *Z* and *E* isomers (90:10). The ratio *Z*/*E* was calculated by ^{1}H NMR integration. A pure sample of (*Z*)-**10c** was isolated by digestion from *n*-hexane.

Yield: 73%, 78% with respect to non-recovered (*E*)-3-ferrocenylacrylonitrile [(*E*)-**4**]; orange solid; mp 80–82 °C (*n*-hexane).

IR (KBr): 3528, 3434, 2203, 1671, 1597, 1526 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 2.22 (s, 3 H), 4.23 (s, 5 H), 4.47 (apparent t, 2 H, *J* = 2 Hz), 4.83 (apparent t, 2 H, *J* = 2 Hz), 5.27 (s, 1 H), 7.23 (br s, 1 H), 7.36 (m, 2 H), 7.54 (m, 2 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 24.7, 70.6, 70.8, 71.1, 78.9, 90.1, 119.4, 128.9, 129.3, 136.2, 139.2, 163.8, 168.7.

ESI-MS: *m*/*z* (%) = 370 [M^+], 388 [M + NH_4]$^+$.

HRMS: *m*/*z* calcd. for $C_{21}H_{18}N_2OFe$: 370.0768; found: 370.0778.

(*Z*)-[2-Cyano-1-(4-methylphenyl)ethenyl]ferrocene [(*Z*)-10d]

After purification by flash chromatography (*n*-hexane–EtOAc, 90:10), (*Z*)-**10d** was obtained.

Yield: 64%; orange solid; mp 106–107 °C (Et_2O) (lit.[5] mp 102 °C).

IR (KBr): 2922, 2203, 1582, 819 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 2.41 (s, 3 H), 4.21 (s, 5 H), 4.47 (m, 2 H), 4.85 (m, 2 H), 5.27 (s, 1 H), 7.15–7.30 (m, 4 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 21.2, 70.4, 70.7, 70.9, 78.8, 89.9, 119.3, 127.9, 128.8, 137.5, 139.3, 164.1.

MS: *m*/*z* (%) = 327 (M^+, 99), 262 (100), 179 (75), 121 (67), 56 (58).

Anal. Calcd for $C_{20}H_{17}NFe$: C, 73.42; H, 5.24; N, 4.28. Found: C, 73.50; H, 5.30; N, 4.27.

(*Z*)-[2-Cyano-1-phenylethenyl]ferrocene [(*Z*)-10e]

After purification by flash chromatography (mixtures of *n*-hexane–EtOAc, 10:1), **10e** was obtained as a mixture of *Z* and *E* isomers (93:7). The ratio *Z*/*E* was calculated by ^{1}H NMR integration. A pure sample of (*Z*)-**10e** was isolated by recrystallization from *n*-hexane–Et_2O.

Yield: 63%, 71% with respect to non-recovered (*E*)-ferrocenylacrylonitrile [(*E*)-**4**)]; orange solid; mp 53–54 °C (lit.[5] mp 68 °C).

IR (KBr): 3055, 2924, 2205, 1583, 823 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 4.22 (s, 5 H), 4.48 (apparent t, 2 H, *J* = 1.9 Hz), 4.84 (apparent t, 2 H, *J* = 1.9 Hz), 5.28 (s, 1 H), 7.38–7.39 (m, 5 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 70.5, 70.7, 71.0, 78.8, 90.5, 119.2, 128.0, 128.2, 129.2, 140.5, 164.3.

MS: *m*/*z* (%) = 313 (M^+, 99), 248 (100), 165 (94), 121 (61), 56 (70).

(*E*)-[2-Cyano-1-(4-acetylaminophenyl)ethenyl]ferrocene [(*E*)-10c]

After purification by flash chromatography (mixtures of *n*-hexane–EtOAc of increasing polarity from 9:1 to 4:6), (*E*)-**10c** was obtained.

Yield: 24%, 31% with respect to non-recovered (*Z*)-3-ferrocenylacrylonitrile [(*Z*)-**4**]; orange solid; mp 165–166 °C (Et_2O).

IR (KBr): 3333, 2202, 1688, 1516 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 2.22 (s, 3 H), 4.16 (s, 5 H), 4.38 (apparent t, 2 H, *J* = 2 Hz), 4.46 (apparent t, 2 H, *J* = 2 Hz), 5.64 (s, 1 H), 7.32 (br s, 1 H), 7.45 (AA′ part of the AA′BB′ system, 2 H, *J* = 8.0 Hz), 7.61 (BB′ part of the AA′BB′ system, 2 H, *J* = 8.0 Hz).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 24.4, 68.7, 70.2, 71.4, 80.7, 89.8, 119.0, 119.3, 129.0, 132.3, 139.3, 165.0, 168.8.

ESI-MS: *m*/*z* (%) = 393 [M + Na]$^+$, 409 [M + K]$^+$.

HRMS: *m*/*z* calcd. for $C_{21}H_{18}N_2OFe$: 370.0768; found: 370.0768.

(*Z*)-3-(4-Methoxyphenyl)-3-(thien-2-yl)-2-propenenitrile [(*Z*)-11b]

After purification by flash chromatography (mixtures of *n*-hexane–EtOAc of increasing polarity from 95:5 to 90:10), **11b** was obtained as a mixture of *Z* and *E* isomers (93:7). The ratio *Z*/*E* was calculated by ^{1}H NMR integration. A pure sample of (*Z*)-**11b** was isolated by vacuum distillation.

Yield: 48%, 56% with respect to non-recovered (*E*)-3-(2-thienyl)acrylonitrile (**5**); colorless oil.

IR (neat): 3104, 2932, 2838, 2206, 1604, 1508, 1253, 1180, 840 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 3.86 (s, 3 H), 5.39 (s, 1 H), 6.91 (AA′ part of the AA′BB′ system, 2 H, *J* = 8.8 Hz), 7.13 (dd, 1 H, *J* = 5.0 and 3.6 Hz), 7.35 (BB′ part of the AA′BB′ system, 2 H, *J* = 8.8 Hz), 7.50–7.58 (m, 2 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 55.3, 91.4, 113.8, 118.3, 127.5, 129.6, 130.1, 131.5, 131.7, 139.3, 154.4, 161.4.

MS: *m*/*z* (%) 241 (M^+, 100), 226 (51), 171 (65).

Anal. Calcd for $C_{14}H_{11}NOS$: C, 69.68; H, 4.59; N, 5.80. Found: C, 69.69; H, 4.77; N, 5.50.

(*Z*)-3-(4-Aminophenyl)-3-(pyridin-3-yl)-2-propenenitrile [(*Z*)-12a]

After purification by flash chromatography (mixtures of *n*-hexane–EtOAc of increasing polarity from 9:1 to 4:6), **12a** was obtained as a mixture of *Z* and *E* isomers (95:5). The ratio *Z*/*E* was calculated by ^{1}H NMR integration. A pure sample of (*Z*)-**12a** was isolated by recrystallization from *n*-hexane–EtOAc.

Yield: 55%, 66% with respect to non-recovered (*E*)-3-(3-pyridyl)acrylonitrile (**6**); pale yellow solid; mp 162–163 °C.

IR (KBr): 3413, 3334, 3170, 2202, 1606, 1553, 1182, 812 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 4.05 (br s, 2 H), 5.71 (s, 1 H), 6.63 (AA′ part of the AA′BB′ system, 2 H, *J* = 8.6 Hz), 7.10 (BB′ part of the AA′BB′ system, 2 H, *J* = 8.6 Hz), 7.30–7.43 (m, 1 H), 7.70–7.83 (m, 1 H), 8.60–8.72 (m, 2 H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 92.6, 115.2, 118.8, 123.9, 127.6, 130.4, 134.2, 137.6, 150.2, 150.7, 151.2, 160.0.

ESI-MS: *m/z* (%) = 222 [M + H]$^+$, 263 [M + MeCN + H]$^+$.

HRMS: *m/z* calcd. for $C_{14}H_{11}N_3$: 221.0953; found: 221.0953.

(*Z*)-3-(4-Methoxyphenyl)-3-(pyridin-3-yl)-2-propenenitrile [(*Z*)-12b]

After purification by flash chromatography (mixtures of *n*-hexane–EtOAc of increasing polarity from 7:3 to 1:1), (*Z*)-**12b** was obtained. A pure sample of (*Z*)-**12b** was isolated by distillation.

Yield: 58%, 65% with respect to non-recovered (*E*)-3-(3-pyridyl)acrylonitrile (**6**); colorless oil; bp 215–220 °C (bulb-to-bulb distillation)/5mmHg.

IR (neat): 3038, 2934, 2211, 1603, 1512, 1254, 1182, 815 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 3.87 (s, 3 H), 5.78 (s, 1 H), 6.90 (AA′ part of the AA′BB′ system, 2 H, *J* = 9 Hz), 7.23 (BB′ part of the AA′BB ′ system, 2 H, *J* = 9 Hz), 7.41 (dd, 1 H, *J* = 7.8 and 4.8 Hz), 7.80 (dt, 1 H, *J* = 7.8 and 1.7 Hz), 8.61 (m, 1 H), 8.71 (dd, 1 H, *J* = 4.8 and 1.7 Hz).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 55.5, 94.2, 114.4, 117.7, 123.3, 129.8, 130.0, 133.3, 136.9, 150.0, 150.8, 159.1, 161.9.

ESI-MS: *m/z* (%) = 237 [M + H]$^+$, 278 [M + MeCN + H]$^+$.

Anal. Calcd for $C_{15}H_{12}N_2O$: C, 76.25; H, 5.12; N, 11.86. Found: C, 75.86; H, 5.14; N, 11.93.

(*Z*)-3-(4-Methylphenyl)-3-(pyridin-3-yl)-2-propenenitrile [(*Z*)-12d]

After purification by flash chromatography (mixtures of *n*-hexane–EtOAc of increasing polarity from 9:1 to 6:4), (*Z*)-**12d** was obtained. A pure sample of (*Z*)-**12d** was isolated by distillation.

Yield: 69%, 80% with respect to non-recovered (*E*)-3-(3-pyridyl)acrylonitrile (**6**); colorless oil; bp 190–195 °C (bulb-to-bulb distillation)/5 mmHg.

IR (neat): 3033, 2922, 2212, 1589, 1411, 811 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 2.40 (s, 3 H), 5.82 (s, 1 H), 7.16 (m, 4 H), 7.40 (dd, 1 H, *J* = 7.8 and 5 Hz), 7.81 (dt, 1 H, *J* = 7.8 and 1.7 Hz), 8.61 (m, 1 H), 8.71 (dd, 1 H, *J* = 5 and 1.7 Hz).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 21.6, 95.8, 117.8, 123.6, 128.4, 129.9, 133.5, 135.2, 137.2, 141.8, 150.2, 151.1, 159.8.

MS: *m/z* (%) = 220 (M$^+$, 100), 205 (94), 180 (52).

Anal. Calcd for $C_{15}H_{12}N_2$: C, 81.79; H, 5.49; N, 12.72. Found: C, 81.62; H, 5.64; N, 12.44.

(*E*)-3-Phenyl-3-(pyridin-3-yl)-2-propenenitrile [(*E*)-12e]

After purification by flash chromatography (mixtures of *n*-hexane–EtOAc of increasing polarity from 9:1 to 6:4), (*E*)-**12e** was obtained. A pure sample of (*E*)-**12e** was obtained by vacuum distillation.

Yield: 39%, 86% with respect to non-recovered (*E*)-cinnamonitrile (**3e**); colorless oil.[16]

IR (neat): 2984, 2918, 2215, 1593, 1414, 803 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 5.78 (s, 1 H), 7.32 (ddd, 1 H, *J* = 8.0, 4.8 and 0.8 Hz), 7.40–7.51 (m, 5 H), 7.58 (dq, 1 H, *J* = 8.0, 2.0 and 1.6 Hz), 8.60 (d, 1 H, *J* = 2.0 Hz), 8.67 (dd, 1 H, *J* = 4.8 and 1.6 Hz).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 97.0, 117.8, 124.0, 129.5, 130.1, 131.2, 135.5, 136.4, 136.7, 149.7, 151.9, 160.6.

ESI-MS: *m/z* (%) = 207 [M + H]$^+$, 248 [M + MeCN + H]$^+$.

Anal. Calcd for $C_{14}H_{10}N_2$: C, 81.53; H, 4.89; N, 13.58. Found: C, 81.12; H, 4.99; N, 13.37.

(*E*)-3-(4-Methylphenyl)-3-(pyridin-3-yl)-2-propenenitrile [(*E*)-12d]

After purification by flash chromatography (mixtures of *n*-hexane–EtOAc of increasing polarity from 9:1 to 7:3), (*E*)-**12d** was obtained. A pure sample of (*E*)-**12d** was isolated by distillation.

Yield: 45%, 93% with respect to non-recovered (*E*)-cinnamonitrile (**3d**); colorless oil; bp 180–185 °C (bulb-to-bulb distillation)/5 mmHg.

IR (neat): 2864, 2765, 2214, 1591, 1413, 824 cm^{-1}.

^{1}H NMR (200 MHz, $CDCl_3$): δ = 2.41 (s, 3 H), 5.71 (s, 1 H), 7.24–7.36 (m, 5 H), 7.58 (dt, 1 H, *J* = 7.9 and 1.9 Hz), 8.59 (d, 1 H, *J* = 2.2 Hz), 8.66 (dd, 1 H, *J* = 4.8 and 1.6 Hz).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 22.0, 96.1, 118.0, 123.8, 129.9, 130.0, 133.7, 135.6, 136.4, 141.5, 149.6, 151.7, 160.4.

ESI-MS: *m/z* (%) = 221 [M + H]$^+$, 262 [M + MeCN + H]$^+$.

Anal. Calcd for $C_{15}H_{12}N_2$: C, 81.79; H, 5.49; N, 12.72. Found: C, 81.72; H, 5.75; N, 12.34.

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References

(1) (a) Heck, R. F. *Acc. Chem. Res.* **1979**, *12*, 146. (b) Heck, R. F. *Org. React. (N.Y.)* **1982**, *27*, 345. (c) Heck, R. F. *Vinyl Substitutions with Organopalladium Intermediates, In Comprehensive Organic Synthesis*, Vol. 4; Trost, B. M.; Fleming, I., Eds.; Pergamon: Oxford, **1991**, Chap. 4.3. (d) De Meijere, A.; Meyer, F. E. *Angew. Chem., Int. Ed. Engl.* **1994**, *33*, 2379. (e) Cabri, W.; Candiani, I. *Acc. Chem. Res.* **1995**, *28*, 2. (f) Negishi, E.; Copéret, C.; Ma, S.; Liou, S.; Liu, F. *Chem. Rev.* **1996**, *96*, 365. (g) Crisp, G. T. *Chem. Soc. Rev.* **1998**, *27*, 427. (h) Beletskaya, I. P.; Cheprakov, A. V. *Chem Rev.* **2000**, *100*, 3009. (i) Whitcombe, N. J.; Kuok Hii, K.; Gibson, S. E. *Tetrahedron* **2001**, *57*, 7449.

(2) For examples of β-arylation of 1,2-disubstituted electron-poor olefins, see: (a) Amorese, A.; Arcadi, A.; Bernocchi, E.; Cacchi, S.; Cerrini, S.; Fedeli, W.; Ortar, G. *Tetrahedron* **1989**, *45*, 813. (b) Moreno-Mañas, M.; Pérez, M.; Pleixats, R. *Tetrahedron Lett.* **1996**, *37*, 7449. (c) Arcadi, A.; Cacchi, S.; Fabrizi, G.; Marinelli, F.; Pace, P. *Tetrahedron* **1996**, *52*, 6983. (d) Moreno-Mañas, M.; Pleixats, R.; Roglans, A. *Synlett* **1997**, 1157. (e) Gürtler, C.; Buchwald, S. L. *Chem.–Eur. J.* **1999**, *5*, 3107. (f) Littke, A. F.; Fu, G. C. *J. Am. Chem. Soc.* **2001**, *123*, 6989. (g) Calò, V.; Nacci, A.; Monopoli, A.; Lopez, L.; di Cosmo, A. *Tetrahedron* **2001**, *57*, 6071. (h) Battistuzzi, G.; Cacchi, S.; Fabrizi, G. *Synlett* **2002**, 439. (i) For Heck reaction of 3-arylacrylates supported on a soluble polymeric support, see: Blettner, C. G.; König, W. A.; Stenzel, W.; Schotten, T. *Tetrahedron Lett.* **1999**, *40*, 2101. (j) For double Heck arylation of acrylates under high-pressure and high-temperature conditions, see: Sugihara, T.; Takebayashi, M.; Kaneko, C. *Tetrahedron Lett.* **1995**, *36*, 5547. (k) For an attractive and efficient stereoselective one-pot double Heck arylation of 2-pyridyldimethyl(vinyl)silanes, see: Itami, K.; Nokami, T.; Ishimura, Y.; Mitsudo, K.; Kamei, T.; Yoshida, J. *J. Am. Chem. Soc.* **2001**, *123*, 11577.

(3) Togni, A.; Hayashi, T. *Ferrocenes: Homogeneous Catalysis, Organic Synthesis, Materials Science*; VCH: Weinheim, **1995**.

(4) (a) Almansa, C.; Gómez, L. A.; Cavalcanti, F. L.; de Arriba, A. F.; Rodríguez, R.; Carceller, E.; García-Rafanell, J.; Forn, J. *J. Med. Chem.* **1996**, *39*, 2197. (b) Almansa, C.; Carceller, E.; González, C. S.; Torres, M. C.; Bartroli, J. J. Uriach and Cia, S.A.; Eur. Pat. EP 669, 333, **1995**; *Chem. Abstr.* **1995**, *123*, 340129u. (c) Blank, B.; Zuccarello, W. A.; Cohen, S. R.; Frishmuth, G. J.; Scaricaciottoli, D. *J. Med. Chem.* **1969**, *12*, 271. (d) Ohnishi, H.; Miyakoshi, M.; Isozaki, M.; Fijitake, M.; Mikami, N.; Yanoshita, R.; Akasofu, H.; Sugizaki, K.; Nakata, N. Terumo Corp., Japan; Eur. Pat. Appl. EP 501876, **1992**; *Chem. Abstr.* **1993**, *118*, 6872.

(5) Mourot, D.; Patin, H. *J. Organomet. Chem.* **1976**, *114*, 89.

(6) Jeffery, T. *Tetrahedron* **1996**, *52*, 10113.

(7) Kasahara, A.; Izumi, T.; Maemura, M. *Bull. Chem. Soc. Jpn.* **1977**, *50*, 1021.

(8) Sévignon, M.; Papillo, J.; Schulz, E.; Lemaire, M. *Tetrahedron Lett.* **1999**, *40*, 5873.

(9) *Handbook of Chemistry and Physics*, 63rd ed; CRC Press Inc.: Boca Raton, **1982-1983**.

(10) DiBiase, S. A.; Lipisko, B. A.; Haag, A.; Wolak, R. A.; Gokel, G. W. *J. Org. Chem.* **1979**, *44*, 4640.

(11) Dolter, R. J.; Curran, C. *J. Am. Chem. Soc.* **1960**, *82*, 4153.

(12) Claisse, J. A.; Gregory, G. I.; Warburton, W. K. US Patent 4012377, **1977**; *Chem. Abstr.* **1978**, *87*, 39491.

(13) Todres, Z. V.; Ermekov, D. S. *J. Organomet. Chem.* **1989**, *369*, 371.

(14) Kasahara, A.; Izumi, T.; Ogihara, T. *J. Heterocycl. Chem.* **1989**, *26*, 597.

(15) Imrie, C.; Loubser, C.; Engelbrecht, P.; McCleland, C. W. *J. Chem. Soc., Perkin Trans. 1* **1999**, 2513.

(16) Ishikawa, F. *Chem. Pharm. Bull.* **1980**, *28*, 1394.