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Synthesis of new functionalized triarylmethanes via Suzuki cross-coupling and Heck-type vinylation reactions

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Abstract. A novel class of triarylmethanes (TRAMs) containing one or two biaryl moieties was synthesized efficiently through the $Pd(PPh_3)_4$-catalyzed Suzuki–Miyaura cross-coupling reaction of brominated TRAMs with arylboronic acid derivatives. We also demonstrate that brominated TRAMs can be efficiently functionalized via a one-pot, two-step Pd-catalyzed Heck-type process. This protocol provides convenient access to diverse vinylated TRAMs that are generally not obtained by using the common synthetic methods for TRAMs.

Keywords. Triarylmethanes, C–C bond formation, Palladium catalysis, Suzuki–Miyaura cross-coupling reactions, Heck-type reactions.

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1. Introduction

Biaryls are privileged templates that are frequently found in natural products, functional materials, polymers, liquid crystals, chiral reagents, and biologically active compounds. They are also employed as building blocks in organic synthesis and ligands for homogeneous catalysis [1,2]. The Suzuki–Miyaura coupling reaction of arylboronic acids with aryl and heteroaryl halides/esters has become a powerful tool for the construction of biaryl scaffolds [3–7]. A new series of diarylmethanes including a biaryl moiety has also been synthesized by Gu *et al.* through the multi-component reaction of organohalides, tosylhydrazide, and arylboronic acids [8]. Recently, Zhou *et al.* have reported the isolation of enantiomeric pairs of Securidanes A and B, as two natural triarylmethanes (TRAMs), from *Securidaca inappendiculata* (Scheme 1A) [9]. To date, to the best of our knowledge, a few TRAMs bearing one or two biphenyl moieties have been synthesized by

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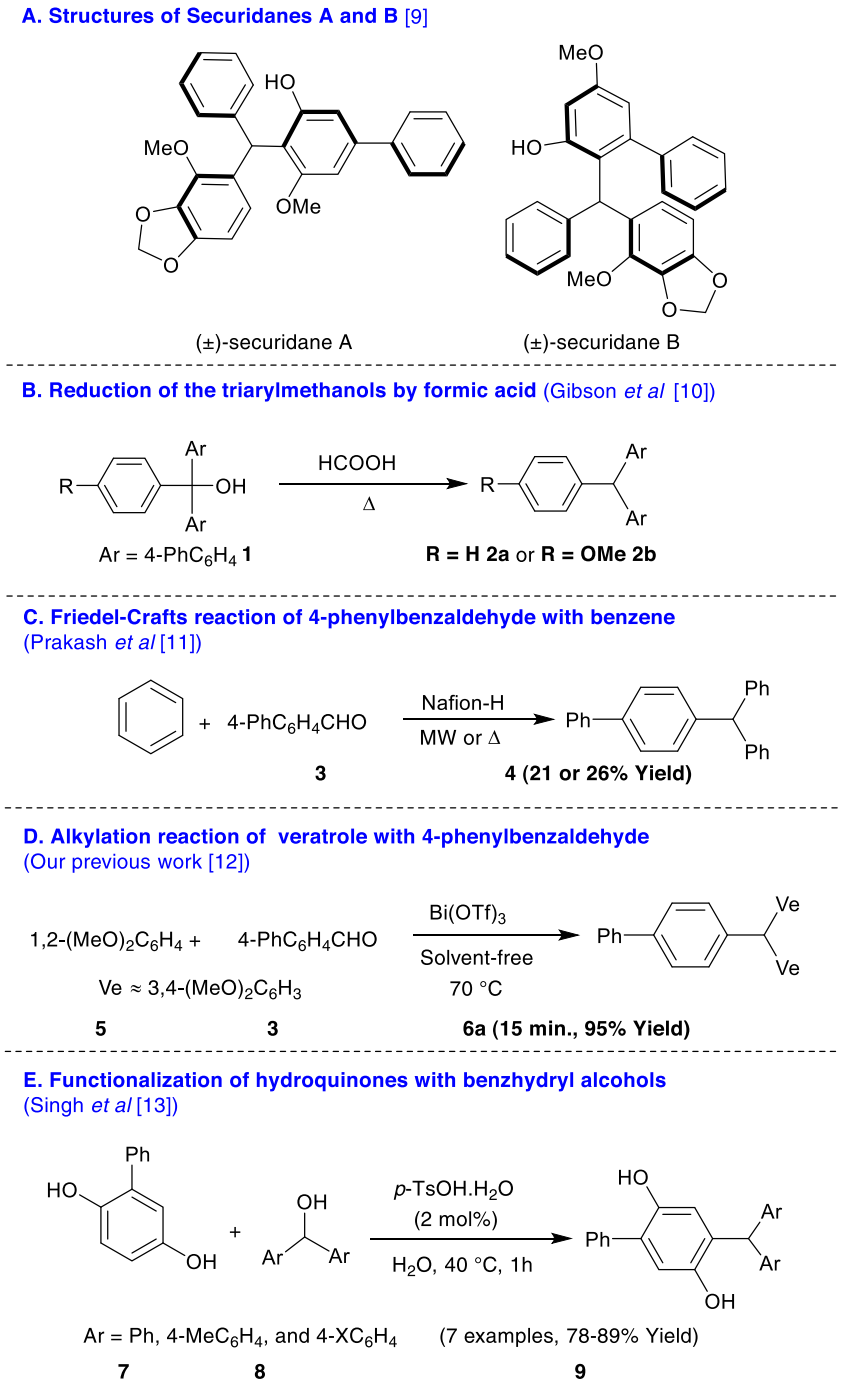


Scheme 1. Structures of Securidanes A and B (1A). Approaches to the synthesis of triarylmethanes containing biaryl unit(s) (1B–E).

means of the reduction of triarylmethanols **1** by formic acid (Scheme 1B) [10], Nafion-H-catalyzed microwave or conventionally heated Friedel–Crafts reaction of 4-phenylbenzaldehyde **3** with benzene

(Scheme 1C) [11], and the Friedel–Crafts alkylation reaction of veratrole **5** with **3** catalyzed by $Bi(OTf)_3$ under solvent-free conditions (Scheme 1D) [12] as well as

p-TsOH-catalyzed functionalization reactions of substituted hydroquinones **7** with benzhydryl alcohols **8** (Scheme 1E) [13]. This limitation on scope originates from three determining factors: (i) Aryl- and heteroarylboronic acids are commercially available with a greater diversity than biarylaldehyde derivatives. (ii) Biarylaldehydes are more expensive than the corresponding arylboronic acids. (iii) The acid-catalyzed reactions of *N*-containing arylaldehydes with arenes generally fail in acidic media due to the coordination of nitrogen site(s) into H^+ or metal cores.

The Mizoroki–Heck-type cross-coupling reaction is a well-known C–C bond forming process, which has been broadly used for vinylation of aryl halides or triflates using Pd(0)-containing catalytic systems [13–17]. In contrast, vinylation of TRAMs has received little attention from researchers to date. Qian *et al.* employed the $Pd(OAc)_2$-catalyzed Heck vinylation reactions of fluorophore templates as the key step for the synthesis of fluorescent probes [18]. The Heck coupling reaction of 1-bromo-3-(diphenylmethyl)benzene with styrylboronic acid has also been used for producing the corresponding vinylated TRAM [19]. Additionally, stilbenoid units have been incorporated into a few tetraarylmethanes using Suzuki coupling reactions [20]. As part of an ongoing program on extending the synthetic applications of TRAMs [12,21–23], we herein describe our efforts toward the functionalization of TRAMs via the Suzuki–Miyaura and Heck-type reactions of brominated TRAMs with arylboronic acids and olefins.

2. Experimental section

2.1. *General considerations*

Unless otherwise stated, all chemicals and solvents were obtained from commercial suppliers and were used without further purification. The solvents used as reaction media were anhydrous, and they were purified according to standard procedures. An aqueous solution of K_2CO_3 (2 M) was freshly prepared in deionized water and was used in reactions without degassing. All the reactions were run in an oven-dried apparatus with dried solvents in an atmosphere of dry nitrogen. Thin layer chromatography (TLC) analyses were performed on pre-coated silica gel F254 plates (commercially available from Merck), and visualized under UV light. Melting points were recorded using a Stuart SMP2 apparatus and were uncorrected. Fourier-transform infrared (FT-IR) spectra were obtained as KBr pellets using a Nicolet Impact 400D spectrophotometer. All ^1H and ^{13}C spectra were recorded on a Varian UNITY Inova 500 MHz spectrometer. Elemental analyses were carried out on a LECO CHNS-932 instrument.

2.2. *General procedures*

2.2.1. *General procedure for the preparation of halogenated TRAMs (Scheme 2)*

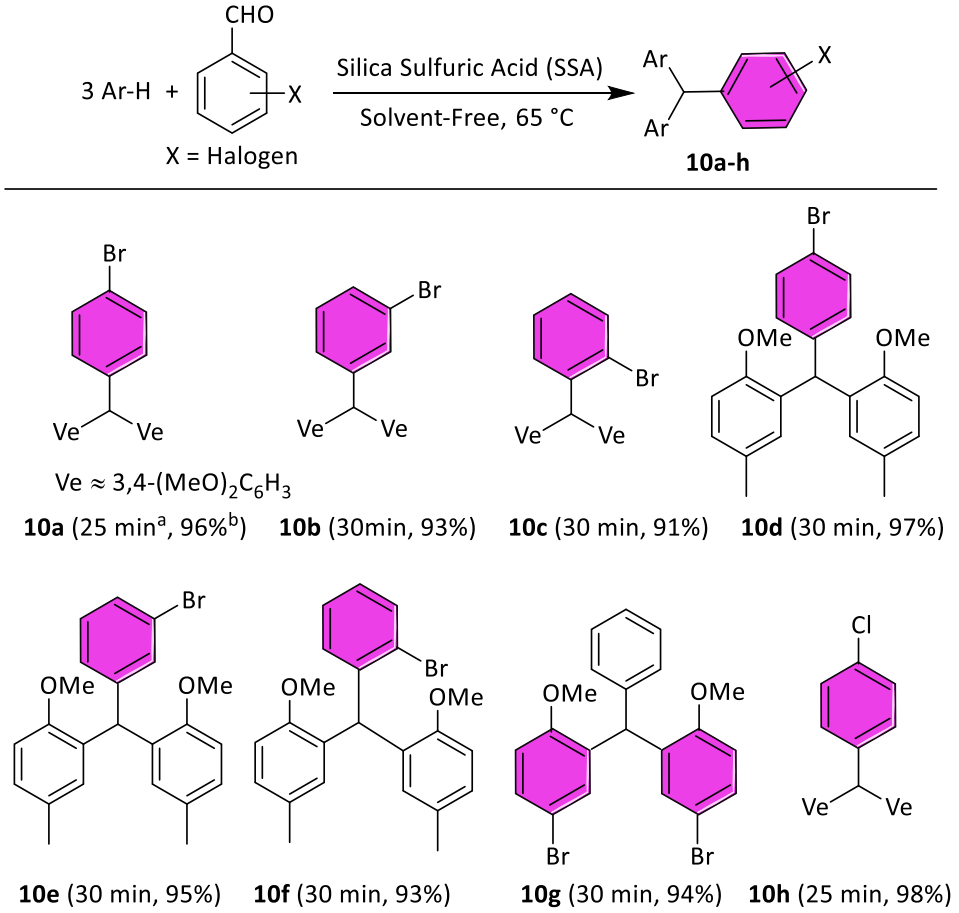
Halogenated TRAMs **10a–h** were prepared following our previously reported method [24]. A mixture of arene (3 mmol), corresponding aldehyde (1 mmol), and silica sulfuric acid (SSA, 200 mg) was stirred at 65 °C for 25–30 min. After completion of the reaction as indicated by TLC (eluent: *n*-hexane/EtOAc 10:4), the reaction mixture was cooled to room temperature and washed twice with absolute EtOH (5 mL). The catalyst was separated by simple filtration, and the crude product was purified by recrystallization from EtOH. The products **10a** [22,24,25], **10b** [12], **10c** [25], **10e** [12], and **10h** [21,26,27] have already been described and matched with bibliographic data.

2,2′-((4-Bromophenyl)methylene)bis(1-methoxy-4-methylbenzene) (10d)

White powder; 398 mg (97%); Mp 153–155 °C; FT-IR (KBr): ν (cm^{-1}) 2998, 2934, 1513, 1463, 1245, 1262, 1139, 1027, 474; ^1H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.35 (d, J = 8.4 Hz, 2H), 7.01 (dd, J_1 = 8.3 Hz, J_2 = 2.4 Hz, 2H), 6.93 (d, J = 8.5 Hz, 2H), 6.77 (d, J = 8.2 Hz, 2H), 6.58 (d, J = 2.5 Hz, 2H), 6.09 (s, 1H, Ar_3CH), 3.67 (s, 6H, OMe), 2.21 (s, 6H, Me); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 155.17, 143.38, 131.76, 131.05, 130.90, 130.61, 129.27, 127.73, 119.42, 110.93, 55.91, 42.70, 20.74; Anal. Calcd for $C_{23}H_{23}BrO_2$: C, 67.16; H, 5.64. Found: C, 67.10; H, 5.59.

2,2′-((2-Bromophenyl)methylene)bis(1-methoxy-4-methylbenzene) (10f)

White powder; 382 mg (93%); Mp 133–135 °C; FT-IR (KBr): ν (cm^{-1}) 2987, 2938, 1613, 1526, 1464, 1127, 1087, 1035, 809, 456; ^1H NMR (500 MHz, $CDCl_3$): δ



Scheme 2. Structures of prepared TRAMs. Reaction conditions: arene (3 mmol), aldehyde (1 mmol), and SSA (200 mg) at 65 °C. [a]Reaction time. [b]Isolated yield.

(ppm) 7.43 (d, J = 7.9 Hz, 1H), 7.09 (t, J = 7.5 Hz, 1H), 6.96–7.00 (m, 1H), 6.92 (dd, J_1 = 8.2 Hz, J_2 = 2.0 Hz, 2H), 6.69 (d, J = 8.3 Hz, 1H), 6.39 (d, J = 1.75 Hz, 2H), 6.25 (s, 1H, Ar_3CH), 3.57 (s, 6H, OMe), 2.09 (s, 6H, Me); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 155.21, 143.52, 132.71, 130.80, 130.55, 130.33, 128.97, 127.61, 126.86, 125.34, 111.11, 55.99, 43.19, 20.83; Anal. Calcd for $C_{23}H_{23}BrO_2$: C, 67.16; H, 5.64. Found: C, 67.11; H, 5.61.

2,2′-(Phenylmethylene)bis(4-bromo-1-methoxybenzene) (10g)

White powder; 427 mg (92%); Mp 148–150 °C; FT-IR (KBr): ν (cm^{-1}) 2935, 1484, 1461, 1244, 1115, 913, 743, 450; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.32 (dd, J_1 = 8.5 Hz, J_2 = 2.5 Hz, 2H), 7.27–7.30 (m, 2H), 7.20–7.26 (m, 1H), 7.04 (d, J = 7.6 Hz, 2H), 6.87 (d, J = 2.5 Hz, 2H), 6.74 (d, J = 8.7 Hz, 2H), 6.06 (s, 1H, Ar_3CH), 3.68 (s, 6H, OMe); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 156.27, 141.90, 134.29, 132.43, 130.35, 129.18, 128.26, 126.36, 112.77, 112.54, 55.86, 43.43; Anal. Calcd for $C_{21}H_{18}Br_2O_2$: C, 54.57; H, 3.93. Found: C, 54.49; H, 3.90.

2.2.2. *General procedure for the Suzuki–Miyaura coupling reactions of TRAMs with arylboronic acid derivatives 6a–l*

An oven-dried 25 mL two-neck flask equipped with a condenser and a magnetic stir bar was charged with $Pd(PPh_3)_4$ (5 mol%), TRAM **10** (1 mmol), and arylboronic acid **11** (1.2 mmol). After performing two cycles of vacuum N_2, degassed tetrahydrofuran (THF,

5 mL) and K_2CO_3 (1 mL of 2 M non-degassed solution) were added using a disposal syringe. The resulting mixture was refluxed for the allotted time, cooled to room temperature, and filtered through a plug of Celite; the volatiles were then removed in vacuo. The crude product was purified by flash chromatography on silica gel (eluent: petroleum ether/methanol 10:1) to obtain the pure product **6a–j**. The products **6k** and **6l** were synthesized using one-pot, double Suzuki coupling reactions of TRAM **10g** with two-fold amounts of **11a** and **11c** under similar conditions.

4-(Bis(3,4-dimethoxyphenyl)methyl)-1,1′-biphenyl (6a)

White powder; 383 mg (87%); Mp 126–128 °C; FT-IR (KBr): ν (cm^{-1}) 3004, 2933, 1591, 1513, 1462, 1266, 1240, 1138, 1027, 753; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.60 (dd, J_1 = 8.1 Hz, J_2 = 1.3 Hz, 2H), 7.54 (d, J = 8.3 Hz, 2H), 7.43 (t, J = 7.6 Hz, 2H), 7.33 (t, J = 7.4 Hz, 1H), 7.20 (d, J = 8.1 Hz, 2H), 6.82 (d, J = 8.4 Hz, 2H), 6.73 (d, J = 2.1 Hz, 2H), 6.66 (dd, J_1 = 8.2 Hz, J_2 = 2.1 Hz, 2H), 5.49 (s, 1H, Ar_3CH), 3.88 (s, 6H, OMe), 3.79 (s, 6H, Me); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 148.86, 147.59, 143.47, 140.81, 139.08, 136.67, 129.66, 128.72, 127.13, 126.95, 126.92, 121.45, 112.88, 111.00, 55.88, 55.87, 55.65; Anal. Calcd for $C_{29}H_{28}O_4$: C, 79.07; H, 6.41. Found: C, 79.13; H, 6.40.

3-(Bis(3,4-dimethoxyphenyl)methyl)-1,1′-biphenyl (6b)

Pale yellow oil; 357 mg (81%); FT-IR (KBr): ν (cm^{-1}) 3018, 2933, 1595, 1512, 1462, 1262, 1184, 1139, 1028, 751, 701; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.55 (d, J = 8.3 Hz, 2H), 7.48 (d, J = 7.2 Hz, 1H), 7.38–7.44 (m, 4H), 7.32–7.35 (m, 1H), 7.14 (d, J = 7.7 Hz, 1H), 6.82 (d, J = 8.3 Hz, 2H), 6.76 (d, J = 1.7 Hz, 2H), 6.66 (dd, J_1 = 8.3 Hz, J_2 = 1.7 Hz, 2H), 5.55 (s, 1H, Ar_3CH), 3.88 (s, 6H, OMe), 3.80 (s, 6H, OMe); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 148.86, 147.59, 144.93, 144.90, 141.11, 136.69, 128.71, 128.68, 128.27, 128.11, 127.24, 127.11, 127.08, 125.12, 121.54, 112.97, 111.11, 58.13, 56.05, 55.85; Anal. Calcd for $C_{29}H_{28}O_4$: C, 79.07; H, 6.41. Found: C, 79.36; H, 6.41.

4-(Bis(2-methoxy-5-methylphenyl)methyl)-1,1′-biphenyl (6c)

White powder; 367 mg (90%); Mp 169–171 °C; FT-IR (KBr): ν (cm^{-1}) 3025, 2923, 1497, 1241, 1077, 1035, 759; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.62 (d, J = 7.4 Hz, 2H), 7.50 (d, J = 8.2 Hz, 2H), 7.43 (t, J = 7.6 Hz, 2H), 7.32 (t, J = 7.4 Hz, 1H), 7.14 (d, J = 8.1 Hz, 2H), 7.02 (dd, J_1 = 8.1 Hz, J_2 = 1.5 Hz, 2H), 6.80 (d, J = 8.3 Hz, 2H), 6.78 (d, J = 1.6 Hz, 2H), 6.21 (s, 1H, Ar_3CH), 3.70 (s, 6H, OMe), 2.22 (s, 6H, Me); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 155.30, 143.31, 141.12, 138.26, 132.41, 130.76, 129.71, 129.24, 128.64, 127.55, 126.90, 126.87, 126.54, 111.03, 56.05, 42.74, 20.79; Anal. Calcd for $C_{29}H_{28}O_2$: C, 85.26; H, 6.91. Found: C, 85.20; H, 6.88.

3-(Bis(2-methoxy-5-methylphenyl)methyl)-1,1′-biphenyl (6d)

White powder; 347 mg (85%); Mp 173–175 °C; FT-IR (KBr): ν (cm^{-1}) 2943, 2883, 1591, 1498, 1470, 1242, 1153, 1035, 806; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.53–7.56 (m, 2H), 7.4–7.45 (m, 3H), 7.29–7.35 (m, 3H), 6.98–7.10 (m, 3H), 6.79 (d, J = 8.2 Hz, 2H), 6.67 (d, J = 2.3 Hz, 2H), 6.23 (s, 1H, Ar_3CH), 3.69 (s, 6H, OMe), 2.21 (s, 6H, Me); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 155.27, 144.62, 141.51, 140.56, 132.34, 130.77, 129.20, 128.57, 128.33, 128.27, 128.19, 127.55, 127.15, 126.94, 124.54, 110.96, 56.02, 43.17, 20.81; Anal. Calcd for $C_{29}H_{28}O_2$: C, 85.26; H, 6.91. Found: C, 85.18; H, 6.86.

1-(4-(Bis(2-methoxy-5-methylphenyl)methyl) phenyl)naphthalen (6e)

White powder; 339 mg (74%); Mp 184–186 °C; FT-IR (KBr): ν (cm^{-1}) 3007, 2952, 1608, 1498, 1439, 1242, 1153, 1072, 1035, 808, 755; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 8.06 (s, 1H), 7.85–7.91 (m, 3H), 7.77 (d, J = 8.3 Hz, 1H), 7.62 (d, J = 8.2 Hz, 2H), 7.45–7.52 (m, 2H), 7.18 (d, J = 8.1 Hz), 7.03 (d, J = 8.0 Hz, 2H), 6.81 (d, J = 8.2 Hz, 2H), 6.70 (s, 1H, Ar_3CH), 3.71 (s, 6H, OMe), 2.23 (s, 6H, Me); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 155.30, 143.46, 138.17, 133.72, 132.48, 132.39, 131.05, 130.91, 130.77, 130.61, 129.82, 129.25, 128.25, 128.12, 127.73, 127.57, 126.83, 126.12, 125.66, 125.54, 125.40, 111.03, 55.91, 42.78, 20.75; Anal. Calcd for $C_{33}H_{30}O_2$: C, 86.43; H, 6.59. Found: C, 86.40; H, 6.61.

3-(4-(Bis(2-methoxy-5-methylphenyl)methyl) phenyl)pyridine (6f)

White powder; 307 mg (75%); Mp 181–183 °C; FT-IR (KBr): ν (cm^{-1}) 2968, 2922, 1608, 1497, 1464, 1241, 1219, 1108, 1035, 772; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 8.88 (d, J = 2.0, 1H), 8.56 (dd, J_1 = 4.9 Hz, J_2 = 1.9 Hz, 1H), 7.90 (td, J_1 = 8.0 Hz, J_2 = 2.0 Hz, 1H), 7.47 (d, J = 8.5 Hz, 2H), 7.36 (dd, J_1 = 7.8 Hz, J_2 = 4.3 Hz, 1H), 7.17 (d, J = 7.8 Hz, 2H), 7.02 (dd, J_1 = 8.5 Hz, J_2 = 2.1 Hz, 2H), 6.79 (d, J = 8.4 Hz, 2H), 6.65 (d,

J = 2.4 Hz, 2H), 6.21 (s, 1H, Ar_3CH), 3.69 (s, 6H, OMe), 2.21 (s, 6H, Me); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 155.26, 148.24, 148.09, 144.41, 136.56, 134.95, 134.07, 132.10, 130.70, 130.01, 129.27, 127.66, 126.66, 126.56, 123.42, 111.01, 60.40, 42.78, 29.68, 20.77; Anal. Calcd for $C_{28}H_{27}NO_2$: C, 82.12; H, 6.65; N, 3.42. Found: C, 82.05; H, 6.60; N, 3.36.

4′-(Bis(2-methoxy-5-methylphenyl)methyl)-[1,1′-biphenyl]-4-carbaldehyde (6g)

White powder; 318 mg (73%); Mp 166–168 °C; FT-IR (KBr): ν (cm^{-1}) 2952, 1883, 1699, 1603, 1557, 1497, 1462, 1242, 1169, 1034, 825, 733; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 10.05 (s, 1H, CHO), 7.94 (d, J = 8.5 Hz, 2H), 7.77 (d, J = 8.4 Hz, 2H), 7.18 (d, J = 8.0 Hz, 2H), 7.03 (dd, J_1 = 7.3 Hz, J_2 = 1.7 Hz, 2H), 6.80 (d, J = 8.3 Hz, 2H), 6.63 (d, J = 2.2 Hz, 2H), 6.22 (s, 1H, Ar_3CH), 3.70 (s, 6H, OMe), 2.22 (s, 6H, Me); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 201.05, 155.24, 147.18, 144.97, 136.76, 134.90, 132.01, 130.70, 130.23, 129.97, 129.27, 127.71, 127.39, 126.85, 110.98, 55.97, 42.85, 20.80; Anal. Calcd for $C_{30}H_{28}O_3$: C, 82.54; H, 6.47. Found: C, 82.47; H, 6.41.

2-(Bis(3,4-dimethoxyphenyl)methyl)-1,1′-biphenyl (6h)

White powder; 299 mg (68%); Mp 117–120 °C; FT-IR (KBr): ν (cm^{-1}) 3055, 2999, 2930, 2831, 1590, 1514, 1463, 1250, 1181, 1183, 1025, 798; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.23–7.33 (m, 6H), 7.10–7.14 (m, 3H), 6.74 (d, J = 8.3 Hz, 2H), 6.52 (dd, J_1 = 8.2 Hz, J_2 = 2.1 Hz, 2H), 6.48 (d, J = 2.2 Hz, 2H), 5.46 (s, 1H, Ar_3CH), 3.85 (s, 6H, OMe), 3.71 (s, 6H, OMe); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 148.61, 147.27, 142.32, 141.90, 141.63, 136.98, 134.58, 130.06, 129.68, 129.28, 128.24, 127.82, 127.37, 127.25, 126.92, 126.86, 124.04, 121.53, 121.84, 110.73, 55.81, 55.76, 52.21; Anal. Calcd for $C_{29}H_{28}O_4$: C, 79.07; H, 6.41. Found: C, 79.00; H, 6.35.

1-(2-(Bis(3,4-dimethoxyphenyl)methyl)phenyl) naphthalen (6i)

Pale yellow oil; 260 mg (53%); FT-IR (KBr): ν (cm^{-1}) 3054, 3002, 2934, 2834, 1591, 1512, 1462, 1414, 1263, 1242, 1184, 1139, 1028, 912, 742; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.87–7.90 (m, 1H), 7.81 (d, J = 8.2 Hz, 1H), 7.70–7.73 (m, 2H), 7.30–7.38 (m, 4H), 7.20–7.24 (m, 1H), 6.78 (d, J = 8.3 Hz, 2H), 6.59 (dd, J_1 = 8.2 Hz, J_2 = 2.1 Hz, 2H), 6.50 (d, J = 2.2 Hz, 2H), 5.51 (s, 1H, Ar_3CH), 3.87 (s, 6H, OMe), 3.67 (s, 6H, OMe); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 174.38, 169.72, 148.69, 147.34, 142.18, 142.16, 139.07, 137.04, 132.89, 132.33, 130.32, 129.85, 128.20, 128.18, 128.02, 127.82, 127.79, 127.64, 127.41, 127.36, 126.21, 125.95, 121.60, 112.89, 110.81, 55.88, 55.83, 55.74, 55.70, 52.54; Anal. Calcd for $C_{33}H_{30}O_4$: C, 80.79; H, 6.16. Found: C, 80.72; H, 6.18.

3-(3-((5-Bromo-2-methoxyphenyl)(phenyl) methyl)-4-methoxyphenyl)pyridine (6j)

White powder; 381 mg (83%); Mp 136–138 °C; FT-IR (KBr): ν (cm^{-1}) 3007, 2936, 2839, 1607, 1486, 1459, 1438, 1289, 1241, 1113, 1021, 806, 708; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 8.68 (dd, J_1 = 2.4 Hz, J_2 = 0.9 Hz, 1H), 8.50 (dd, J_1 = 4.8 Hz, J_2 = 1.7 Hz, 1H), 7.68 (qd, J_1 = 8.0 Hz, J_2 = 2.4 Hz, J_3 = 1.7 Hz, 1H), 7.33 (dd, J_1 = 8.7 Hz, J_2 = 2.6 Hz, 1H), 7.26–7.31 (m, 3H), 7.20–7.24 (m, 1H), 7.05–7.10 (m, 2H), 7.06 (d, J = 1.7 Hz, 1H), 6.98 (d, J = 8.5 Hz, 1H), 6.93 (dd, J_1 = 2.6 Hz, J_2 = 0.6 Hz, 1H), 6.76 (d, J = 8.8 Hz, 1H), 6.17 (s, 1H, Ar_3H), 3.76 (s, 3H, OMe), 3.69 (s, 3H, OMe); ^{13}C NMR (126 MHz, $CDCl_3$): δ (ppm) 157.36, 156.37, 148.01, 147.71, 142.39, 136.33, 134.64, 133.78, 132.67, 132.45, 130.28, 129.61, 129.21, 128.61, 128.22, 126.30, 123.42, 112.74, 112.52, 111.28, 55.93, 55.82, 43.53; Anal. Calcd for $C_{26}H_{22}BrNO_2$: C, 67.83; H, 4.82; N, 3.04. Found: C, 67.77; H, 4.75; N, 2.98.

3,3″-(Phenylmethylene)bis(4-methoxy-1,1′-biphenyl) (6k)

White powder; 356 mg (78%); Mp 65–67 °C; FT-IR (KBr): ν (cm^{-1}) 3028, 3000, 2933, 1605, 1483, 1462, 1242, 1110, 1075, 1025, 760, 700; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.56–7.61 (m, 6H), 7.45–7.49 (m, 4H), 7.40–7.44 (m, 2H), 7.30–7.40 (m, 7H), 7.06 (d, J = 8.4 Hz, 2H), 6.49 (s, 1H, Ar_3CH), 3.84 (s, 6H, OMe); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 157.14, 143.60, 141.28, 133.15, 132.96, 129.52, 129.00, 128.78, 128.20, 126.81, 126.58, 126.15, 126.11, 111.29, 55.95, 43.79; Anal. Calcd for $C_{33}H_{28}O_2$: C, 86.81; H, 6.18. Found: C, 86.75; H, 6.15.

3,3′-((Phenylmethylene)bis(4-methoxy-3,1-phenylene))dipyridine (6l)

White powder; 248 mg (54%); Mp 190–192 °C; FT-IR (KBr): ν (cm^{-1}) 3027, 2931, 2836, 1607, 1503, 1474, 1288, 1249, 1113, 1065, 1022, 801, 751, 712; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 8.66 (d, J = 2.3 Hz, 2H), 8.47 (dd, J_1 = 4.8 Hz, J_2 = 1.6 Hz, 2H), 7.66–7.69 (m, 2H), 7.46 (dd, J_1 = 8.4 Hz, J_2 = 2.4 Hz, 2H), 7.20–7.31 (d, J = 2.3 Hz, 2H), 6.99 (d, J = 8.5 Hz, 2H), 6.26 (s, 1H, Ar_3CH), 3.77 (s, 6H, OMe); ^{13}C NMR

(125 MHz, $CDCl_3$): δ (ppm) 157.47, 149.35, 148.23, 147.98, 147.65, 142.84, 136.39, 134.42, 133.76, 133.02, 129.54, 129.23, 128.59, 128.18, 126.22, 123.78, 123.41, 111.27, 55.87, 43.71; Anal. Calcd for $C_{31}H_{26}N_2O_2$: C, 81.20; H, 5.72; N, 6.11. Found: C, 81.15; H, 5.70; N, 6.06.

2.2.3. *General procedure for the Mizoroki–Heck coupling reactions of TRAMs with olefins 13a–j.*

An oven-dried 25 mL two-neck flask equipped with a condenser and a stir bar was charged with $PdCl_2$ (0.05 mmol), PPh_3 (0.1 mmol), and LiBr (0.1 mmol); two cycles of vacuum N_2 were performed. Anhydrous dimethylformamide (DMF, 2 mL) was added, and the resulting suspension was heated at 140 °C for 30 min. After cooling the yellowish mixture to room temperature, Et_3N (2 mmol) was added. This was followed by the addition of a solution of TRAM **10** (1 mmol) and olefin **12** (2 mmol) in anhydrous DMF (3 mL). The reaction mixture was heated at 100 °C for 36 h, allowed to reach room temperature, and filtered through a plug of Celite. After the removal of volatiles in vacuo, the crude product was purified by flash chromatography on silica gel using *n*-hexane/EtOAc (5:1) as an eluent to obtain the corresponding pure product **13a–j**.

Methyl (*E*)-3-(4-(bis(2-methoxy-5-methylphenyl) methyl)phenyl)acrylate (13a)

White powder; 371 mg (89%); Mp 160–162 °C; FT-IR (KBr): ν (cm^{-1}) 3022, 2948, 2834, 1719, 1634, 1605, 1498, 1463, 1242, 1168, 1035, 858, 757; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.69 (d, *J* = 16.0 Hz, 1H), 7.42 (d, *J* = 7.2 Hz, 2H), 7.09 (d, *J* = 8.1 Hz, 2H), 7.02 (d, *J* = 7.1 Hz, 2H), 7.78 (d, *J* = 8.3 Hz, 2H), 6.61 (s, 2H), 6.41 (d, *J* = 16.0 Hz, 1H), 6.16 (s, 1H), 3.80 (s, 3H), 3.67 (s, 6H), 2.21 (s, 6H); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 167.64, 155.20, 147.28, 145.09, 131.82, 131.72, 130.67, 129.80, 129.27, 127.82, 127.75, 116.66, 110.93, 55.93, 51.60, 43.11, 20.76; Anal. Calcd for $C_{27}H_{28}O_4$: C, 77.86; H, 6.78. Found: C, 77.80; H, 6.72.

***Tert*-butyl (*E*)-3-(4-(bis(2-methoxy-5-methyl phenyl)methyl)phenyl)acrylate (13b)**

White powder; 389 mg (85%); Mp 147–149 °C; FT-IR (KBr): ν (cm^{-1}) 3023, 2956, 2871, 1711, 1635, 1606, 1498, 1462, 1243, 1169, 1071, 1035, 807, 734; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.73 (d, *J* = 16.0 Hz, 1H), 7.41 (d, *J* = 8.3 Hz, 2H), 7.08 (d, *J* = 8.3 Hz, 2H), 7.01 (dd, J_1 = 8.2 Hz, J_2 = 2.7 Hz, 1H), 6.78 (d, *J* = 8.3 Hz, 2H), 6.60 (d, *J* = 2.3 Hz, 2H), 6.40 (d, *J* = 16.0 Hz, 1H), 6.16 (s, 6H, Ar_3CH), 3.67 (s, 3H, 6H, OMe), 2.20 (s, 6H, Me), 1.54 (s, 9H, Bu^t); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 167.62, 155.21, 147.27, 145.07, 131.82, 131.73, 130.67, 129.78, 129.28, 127.79, 127.74, 116.64, 110.96, 55.95, 55.91, 51.54, 28.36, 20.74; Anal. Calcd for $C_{30}H_{34}O_4$: C, 78.57; H, 7.47. Found: C, 78.51; H, 7.40.

(*E*)-2,2′-((4-Styrylphenyl)methylene)bis(1-methoxy-4-methylbenzene) (13c)

White powder; 308 mg (71%); Mp 105–107 °C; FT-IR (KBr): ν (cm^{-1}) 3003, 2938, 2836, 1837, 1558, 1533, 1458, 1416, 1342, 1258, 1233, 1165, 1028, 876, 763; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.88 (d, *J* = 8.2 Hz, 2H), 7.67 (d, *J* = 8.2 Hz, 2H), 7.56 (d, *J* = 7.5 Hz, 2H), 7.32–7.43 (m, 3H), 7.16 (d, *J* = 16.4 Hz, 1H), 7.00 (dd, J_1 = 8.2 Hz, J_2 = 1.7 Hz, 2H), 6.92 (d, *J* = 8.4 Hz, 2H), 6.77 (d, *J* = 8.3 Hz, 2H), 6.57 (d, *J* = 1.7 Hz, 2H), 6.08 (s, 1H), 3.66 (s, 6H), 2.20 (s, 6H); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 155.27, 131.75, 131.06, 130.91, 130.72, 130.62, 129.64, 129.26, 129.21, 128.61, 127.73, 127.56, 126.38, 126.51, 110.96, 110.96, 55.91, 42.69, 20.75; Anal. Calcd for $C_{31}H_{30}O_2$: C, 85.68; H, 6.96. Found: C, 85.60; H, 6.93.

Methyl (*E*)-3-(4-(bis(3,4-dimethoxyphenyl)methyl) phenyl)acrylate (13d)

Pale yellow oil; 390 mg (87%); FT-IR (KBr): ν (cm^{-1}) 2999, 2951, 2835, 1716, 1635, 1604, 1512, 1462, 1415, 1324, 1264, 1169, 1140, 1028, 731; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.67 (d, *J* = 16.15 Hz, 1H), 7.45 (d, *J* = 8.4 Hz, 2H), 7.14 (d, *J* = 8.2 Hz, 2H), 6.79 (d, *J* = 8.3 Hz, 2H), 6.65 (d, *J* = 2.2 Hz, 2H), 6.58 (dd, J_1 = 8.6 Hz, J_2 = 1.8 Hz, 2H), 6.41 (d, *J* = 16.0 Hz, 1H), 5.45 (s, 1H, Ar_3CH), 3.85 (s, 6H, OMe), 3.79 (s, 3H, CO_2Me), 3.76 (s, 6H, OMe); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 160.78, 148.84, 147.62, 147.01, 144.56, 136.04, 132.46, 129.80, 128.07, 121.34, 117.32, 112.64, 110.91, 55.87, 55.84, 55.81, 51.68; Anal. Calcd for $C_{27}H_{28}O_6$: C, 72.30; H, 6.29. Found: C, 72.25; H, 6.25.

Methyl (*E*)-3-(3-(bis(3,4-dimethoxyphenyl)methyl) phenyl)acrylate (13e)

Pale yellow oil; 351 mg (78%); FT-IR (KBr): ν (cm^{-1}) 3003, 2932, 2835, 1604, 1512, 1463, 1415, 1262, 1139, 1062, 754; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 8.04 (d, *J* = 15.8 Hz, 1H), 7.55 (dd, J_1 = 7.6 Hz,

J_2 = 1.1 Hz, 1H), 7.23–7.30 (m, 2H), 6.93 (d, J = 7.6 Hz, 1H), 6.77 (d, J = 8.3 Hz, 2H), 6.64 (d, J = 1.4 Hz, 2H), 6.53 (dd, J_1 = 8.2 Hz, J_2 = 1.7 Hz, 2H), 6.27 (d, J = 15.8 Hz, 1H), 3.86 (s, 6H), 3.77 (s, 6H), 3.77 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 167.13, 148.89, 147.59, 143.58, 142.60, 135.67, 133.70, 129.80, 129.72, 126.88, 126.80, 121.64, 119.71, 112.85, 110.95, 55.82, 55.80, 52.28, 51.59; Anal. Calcd for $C_{27}H_{28}O_6$: C, 72.30; H, 6.29. Found: C, 72.25; H, 6.23.

Methyl (*E*)-3-(2-(bis(3,4-dimethoxyphenyl)methyl) phenyl)acrylate (13f)

White powder; 287 mg (64%); Mp 115–117 °C; FT-IR (KBr): ν (cm^{-1}) 3000, 2950, 2834, 1716, 1631, 1512, 1462, 1316, 1263, 1243, 1139, 1027, 757; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 8.04 (d, J = 15.8 Hz, 1H), 7.55 (dd, J_1 = 7.4 Hz, J_2 = 1.8 Hz, 1H), 7.23–7.32 (m, 3H), 6.93 (dd, J_1 = 7.5 Hz, J_2 = 1.7 Hz, 1H), 6.78 (d, J = 8.3 Hz, 2H), 6.64 (d, J = 2.1 Hz, 2H), 6.53 (dd, J_1 = 8.3 Hz, J_2 = 2.1 Hz, 2H), 6.27 (d, J = 15.8 Hz, 1H), 5.76 (s, 6H), 3.86 (s, 6H), 3.77 (s, 6H), 3.75 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 167.16, 148.86, 147.56, 143.60, 142.60, 135.66, 133.69, 129.82, 129.76, 126.89, 126.82, 121.63, 119.71, 112.78, 110.89, 55.82, 55.80, 52.28, 51.16; Anal. Calcd for $C_{27}H_{28}O_6$: C, 72.30; H, 6.29. Found: C, 72.32; H, 6.25.

(*E*)-4,4′-((3-Styrylphenyl)methylene)bis(1,2-dimethoxybenzene) (13g)

White powder; 317 mg (68%); Mp 97–99 °C; FT-IR (KBr): ν (cm^{-1}) 2998, 2936, 1840, 1560, 1513, 1449, 1412, 1340, 1265, 1249, 1135, 1052, 995, 854, 761; ^{1}H NMR (500 MHz, DMSO-d_6): δ (ppm) 7.57 (d, J = 7.7 Hz, 2H), 7.48 (d, J = 7.8 Hz, 1H), 7.17–7.36 (m, 7H), 6.98 (d, J = 7.7 Hz, 1H), 6.87 (d, J = 8.3 Hz, 2H), 6.67 (d, J = 2.1 Hz, 2H), 6.58 (dd, J_1 = 8.3 Hz, J_2 = 2.1 Hz, 2H), 5.48 (s, 1H), 3.70 (s, 6H), 3.63 (s, 6H, 6H); ^{13}C NMR (125 MHz, DMSO-d_6): δ (ppm) 148.99, 147.73, 145.34, 137.41, 137.40, 136.85, 129.11, 129.04, 128.95, 128.45, 128.68, 128.06, 128.01, 126.93, 124.42, 121.49, 113.53, 112.15, 55.94, 55.42; Anal. Calcd for $C_{31}H_{30}O_4$: C, 79.80; H, 6.48. Found: C, 79.74; H, 6.42.

(*E*)-4,4′-((2-Styrylphenyl)methylene)bis(1,2-dimethoxybenzene) (13h)

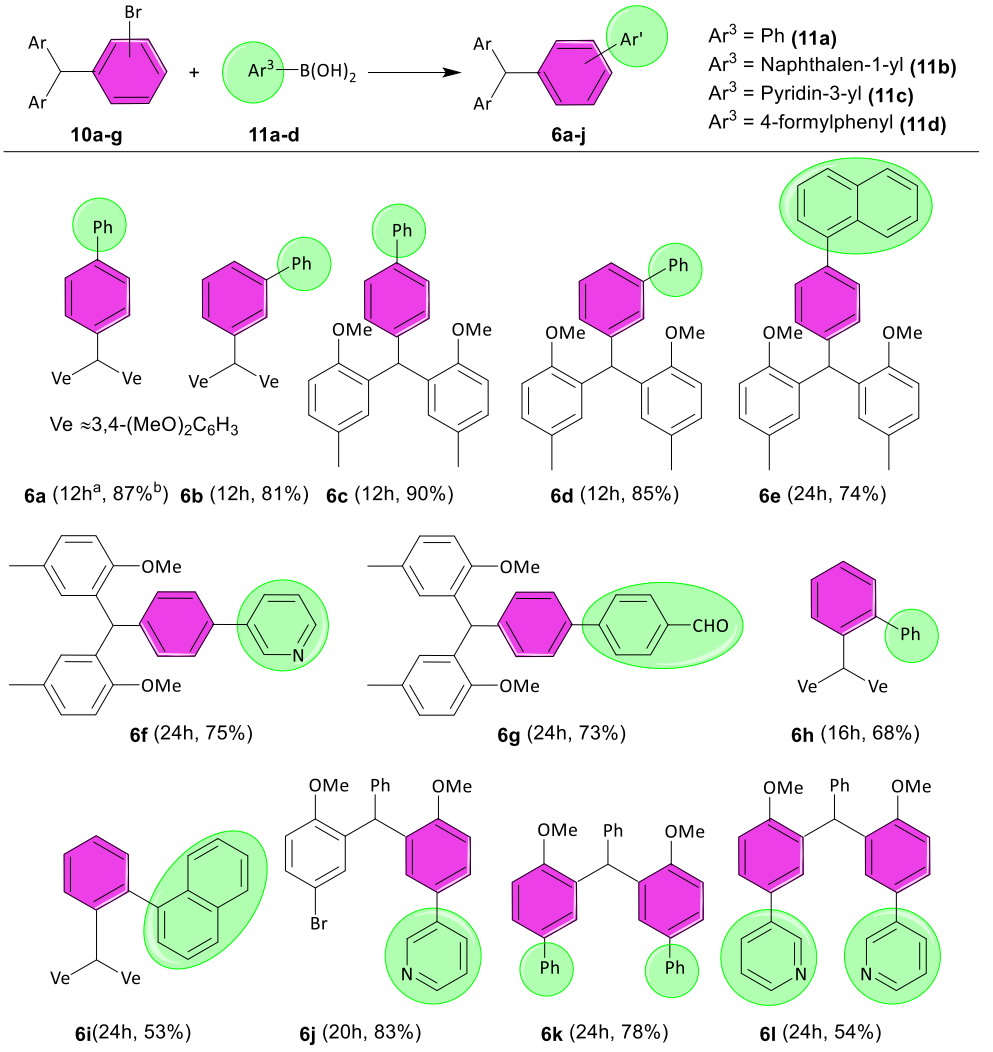
White powder; 294 mg (63%); Mp 101–103 °C; FT-IR (KBr): ν (cm^{-1}) 2995, 2935, 1835, 1589, 1512, 1449, 1340, 1263, 1248, 1184, 1136, 1025, 761; ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.61 (d, J = 7.5 Hz, 1H), 7.33–7.37 (m, 3H), 7.17–7.28 (m, 3H), 6.93 (d, J = 16.1 Hz, 1H), 6.89 (dd, J_1 = 7.6 Hz, J_2 = 1.4 Hz, 1H), 6.80 (d, J = 8.3 Hz, 2H), 6.69 (d, J = 2.1 Hz, 2H), 6.60 (dd, J_1 = 10.7 Hz, J_2 = 2.1 Hz, 2H), 5.74 (s, 1H), 3.87 (s, 6H), 3.77 (s, 6H); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 148.93, 147.56, 141.98, 137.58, 136.76, 136.19, 130.76, 129.54, 128.62, 127.59, 127.39, 126.87, 126.67, 126.47, 126.20, 121.68, 112.98, 111.04, 55.84, 52.78; Anal. Calcd for $C_{31}H_{30}O_4$: C, 79.80; H, 6.48. Found: C, 79.75; H, 6.43.

(*E*)-4,4′-((2-(4-Chlorostyryl)phenyl)methylene) bis(1,2-dimethoxybenzene) (13i)

White powder; 302 mg (60%); Mp 131–133 °C; FT-IR (KBr): ν (cm^{-1}) 3020, 2933, 2834, 1590, 1512, 1462, 1414, 1263, 1139, 1028, 812, 754; ^{1}H NMR (500 MHz, DMSO-d_6): δ (ppm) 7.68 (dd, J_1 = 7.6 Hz, J_2 = 1.6 Hz, 1H), 7.51 (d, J = 16.2 Hz, 1H), 7.47 (d, J = 7.1 Hz, 2H), 7.32 (t, J = 7.7 Hz, 2H), 7.17–7.25 (m, 3H), 7.01 (d, J = 16.2 Hz, 1H), 6.86 (d, J = 8.2 Hz, 2H), 6.81 (d, J = 2.1 Hz, 2H), 6.52 (dd, J_1 = 8.2 Hz, J_2 = 2.0 Hz, 2H), 5.51 (s, 1H, Ar_3CH), 3.69 (s, 6H, OMe), 3.63 (s, 6H, OMe); ^{13}C NMR (126 MHz, DMSO-d_6): δ (ppm) 149.02, 147.62, 142.70, 137.75, 136.52, 136.14, 129.97, 129.41, 129.06, 129.03, 126.89, 126.85, 126.59, 126.53, 126.05, 121.74, 113.68, 112.06, 55.92, 55.89, 55.85, 55.82, 51.87; Anal. Calcd for $C_{31}H_{29}ClO_4$: C, 74.32; H, 5.83. Found: C, 74.28; H, 5.80.

3-(4-(Bis(3,4-dimethoxyphenyl)methyl)phenyl) acrylonitrile (13j)

White powder; 266 mg (64%) (E:Z = 60:40 based on ^{1}H NMR spectrum); Mp 98–101 °C; FT-IR (KBr): ν (cm^{-1}) 3003, 2932, 2835, 2215, 1604, 1512, 1463, 1415, 1262, 1244, 1139, 1026, 966, 800, 754; ^{1}H NMR of (*E*)-isomer (500 MHz, $CDCl_3$): δ (ppm) 7.60 (d, J = 16.8 Hz, 1H), 7.56 (d, J = 8.4 Hz, 2H), 7.16 (d, J = 8.3 Hz, 2H), 6.86 (d, J = 8.3 Hz, 2H), 6.72 (d, J = 2.0 Hz, 2H), 6.55 (dd, J_1 = 8.2 Hz, J_2 = 2.0 Hz, 2H), 6.38 (d, J = 16.8 Hz, 1H), 5.49 (s, 1H), 3.70 (s, 6H), 3.63 (s, 6H); ^{1}H NMR of (*Z*)-isomer (500 MHz, $CDCl_3$): δ (ppm) 7.73 (d, J = 8.4 Hz, 2H), 7.35 (d, J = 14.0 Hz, 1H), 7.23 (d, J = 9.2 Hz, 2H), 6.87 (d, J = 8.4 Hz, 2H), 6.74 (d, J = 2.0 Hz, 2H), 6.57 (dd, J_1 = 8.1 Hz, J_2 = 2.0 Hz, 2H), 5.81 (d, J = 12.1 Hz, 1H), 5.51 (s, 1H), 3.70 (s, 6H), 3.63 (s, 6H); ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 150.74, 149.02, 148.27, 148.05, 136.46, 132.22, 129.96, 129.11, 128.20, 121.44, 113.43, 112.18, 110.03, 55.94, 55.33; Anal. Calcd for $C_{26}H_{25}NO_4$: C, 75.16; H, 6.07; N, 3.37. Found: C, 75.10; H, 6.00; N, 3.30.



Scheme 3. Synthesis of TRAMs containing biaryl unit(s). Reaction conditions: TRAMs **10** (1 mmol), **11** (1.2 mmol), $Pd(PPh_3)_4$ (5 mol%), K_2CO_3 (1 mL, 2 M), and THF (5 mL) in N_2 atmosphere and under reflux conditions. [a]Reaction time. [b]Isolated yield.

3. Results and discussion

3.1. *Synthesis of new TRAMs bearing one or two biaryl moieties via [Pd]-catalyzed Suzuki–Miyaura cross-coupling reactions*

Tetrakis(triphenylphosphine)palladium(0) is a commercially available product that has been traditionally used as a convenient catalyst in coupling reactions [7,28–30]. We therefore decided to investigate the coupling reaction of brominated TRAMs **10a–g** with arylboronic acids **11a–d** in the presence of $Pd(PPh_3)_4$ for building TRAMs containing biaryl unit(s). Accordingly, the treatment of TRAM **10a** with phenylboronic acid **11a** in the presence of 5 mol% $Pd(PPh_3)_4$ under optimal reaction conditions (see Supporting information) resulted in the formation of coupling product **6a** in 87% yield (Scheme 3).

Likewise, brominated TRAMs **10a–h** were subjected to the Suzuki coupling reaction with arylboronic acid derivatives **11a–d** to produce the corresponding coupling products, and the results are shown in Scheme 3. The reaction of brominated TRAMs **10b**, **10d**, and **10e** with phenylboronic acid **11a** proceeded efficiently, and the desired coupling

products **6b–d** were obtained in yields ranging from 81% to 90%. We next used naphthalen-1-ylboronic acid **11b**, pyridin-3-ylboronic acid **11c**, and (4-formylphenyl)boronic acid **11d** as coupling partners in the reaction with TRAM **10d** under optimal conditions, and products **6e–g** were acquired in 74%, 75%, and 73% yields, respectively. Then we examined the reactivity of TRAM **10c** in the coupling reaction with arylboronic acids. Although the reaction of TRAM **10c** with phenylboronic acid **11a** generated product **6h** in 68% yield after 16 h, product **6i** was isolated in moderate yield via the coupling reaction of **10c** with naphthalen-1-ylboronic acid **11b** after 24 h. Accordingly, *ortho*-brominated TRAM **10c** displayed significant resistance toward the coupling reaction with arylboronic acids probably due to the steric effects of the diveratrylmethyl group (Ve_2CH–). In addition, the reaction of chlorinated TRAM **10h** with phenylboronic acids **11a** did not proceed efficiently even after 24 h due to the strength of the C–Cl bond. This result proved that brominated TRAMs have been selected properly as substrates for this procedure. On the other hand, we found this protocol suitable for the indirect synthesis of unsymmetrical TRAMs. For example, when we treated TRAM **10g** with pyridin-3-ylboronic acid **11c** under optimal conditions, unsymmetrical TRAM **6j** was obtained selectively in 83% yield after 20 h as depicted in Scheme 3. To the best of our knowledge, there exist a few examples of TRAM derivatives containing two biaryl moieties. Moreover, this kind of TRAM could not be synthesized by Friedel–Crafts alkylation reactions of aldehydes. Double Suzuki–Miyaura coupling reactions using palladium catalysts have been repeatedly reported in organic synthesis [31–35]. Surprisingly, one-pot, double Suzuki coupling reactions of TRAM **10g** with two-fold amounts of **11a** and **11c** under optimal reaction conditions resulted in products **6k** and **6l** in 78% and 54% yields, respectively. Furthermore, this protocol may offer an efficient approach for the induction of chirality into TRAM molecules by constructing a biaryl or aryl(heteroaryl) moiety on them.

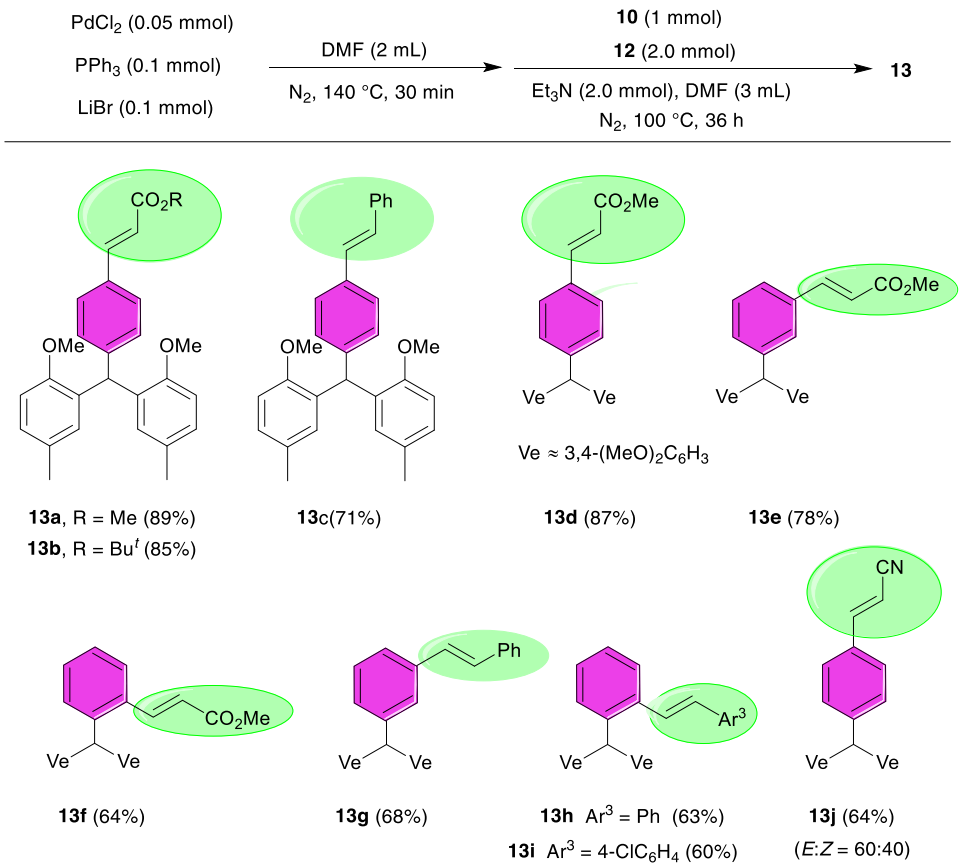
3.2. *Synthesis of vinylated TRAMs through Mizoroki–Heck cross-coupling reaction of brominated TRAMs with olefins*

Prompted by the results obtained in the Suzuki coupling reactions, we became interested in investigating the Pd-catalyzed *Heck* coupling reactions of brominated TRAMs with olefins. There are various reports in the literature on the use of $PdCl_2(PPh_3)_2$ in coupling reactions [4,36–39]. We initially set up a one-pot, two-step protocol to react TRAM **10d** with methyl acrylate **12a** in the presence of in situ generated $PdCl_2(PPh_3)_2$ as a pre-catalyst. As depicted in Scheme 4, the expected coupling product **10a** was isolated in 89% yield under optimal reaction conditions (see Supporting information).

We decided to also examine the generality of this protocol, and the results are illustrated in Scheme 4. The Heck coupling reaction of TRAM **10d** with *tert*-butyl acrylate **12b** produced the coupling product **13b** in 85% yield. When styrene **12c** was used as the coupling partner in the reaction with TRAM **10d**, the respective (*E*)-stilbene product **13c** was isolated in 71% yield. However, triarylmethane **10d** failed to react with acrylamide **12d** under optimal conditions. We then turned our attention to the vinylation–functionalization of TRAMs **10a–c** containing two veratryl moieties. Under optimal conditions, these precursors underwent vinylation with **12a** to produce the corresponding aryl acrylates **13d–f** in good to high yields. Substrate **10b** also reacted smoothly with **12c** to produce the olefination product **13g** in 68% yield. The reaction of TRAM **10c** with **12c** and 4-chlorostyrene **12e** proceeded well to generate the expected (*E*)-stilbene derivatives **13h** and **13i** in slightly lower yields. These results indicate that the substrates containing a sterically hindered diveratrylmethyl substituent (Ve_2CH–) at the *ortho*-position of the C–Br bond are less reactive in olefination reactions. Moreover, acrylonitrile **12f** reacted with TRAM **10d** producing a non-separable mixture of *E*- and *Z*-isomers of aryl acrylonitrile **13j** in 64% yield in an approximate ratio of 60:40, respectively (based on ^{1}H NMR of the mixture; see Supporting information). Compounds **13a–j** produced via this procedure could not be synthesized by means of the common synthetic methods for TRAMs. Furthermore, our initial evaluation showed that these compounds can be promising building blocks in organic synthesis. This study is currently ongoing in our laboratory.

4. Conclusion

In summary, symmetrical and unsymmetrical TRAMs bearing one or two biaryl units can be



Scheme 4. Structures of vinylated TRAMs produced through $PdCl_2(PPh_3)_2$-catalyzed Mizoroki–Heck-type reaction of brominated TRAMs with olefins.

synthesized in good to high yields from the Suzuki–Miyaura cross-coupling reaction of brominated TRAMs with arylboronic acids in the presence of $Pd(PPh_3)_4$, which is a cheap and readily available catalyst. We have also developed a one-pot, two-step Heck-type coupling procedure for the efficient vinylation of brominated TRAMs. This protocol provides an exclusive and efficient method for the synthesis of functionalized TRAMs, which cannot be produced by conventional methods. The obtained products can be used as building blocks in organic transformations or as ligands for catalysis objectives.

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Supplementary data

Supporting information for this article is available on the journal's website under https://doi.org/10.5802/crchim.34 or from the author.

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