ORGANIC
LETTERS

2010
Vol. 12, No. 3
592−595

Synthesis of α,ω-Diarylbutadienes and -Hexatrienes via Decarboxylative Coupling of Cinnamic Acids with Vinyl Bromides under Palladium Catalysis

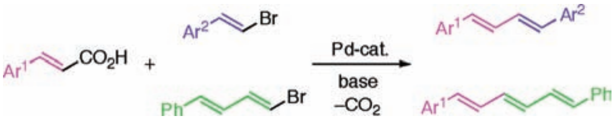
Mana Yamashita, Koji Hirano, Tetsuya Satoh,* and Masahiro Miura*

Department of Applied Chemistry, Faculty of Engineering, Osaka University,
Suita, Osaka 565-0871, Japan

satoh@chem.eng.osaka-u.ac.jp; miura@chem.eng.osaka-u.ac.jp

Received December 3, 2009

ABSTRACT



Readily available cinnamic acid derivatives such as ferulic acid couple with β-bromostyrenes and 1-bromo-4-phenylbutadiene under palladium catalysis accompanied by decarboxylation to produce the corresponding α,ω-diarylbutadienes and -hexatrienes, respectively. Some of the products exhibit solid-state fluorescence.

Since polyene structures can be seen in natural products[1] and organic materials,[2] development of their construction methods has attracted considerable attention in organic synthesis. Particularly, α,ω-diarylated polyenes such as 1,4-diaryl-1,3-butadiene and 1,6-diaryl-1,3,5-hexatriene derivatives are highly important for their application to liquid crystals, illuminants, and nonlinear optical materials.[3] Their syntheses have been traditionally conducted by Wittig-type or transition-metal-catalyzed cross-coupling reactions.[4] The major drawback of these reactions is the involvement of phosphorus- and metal-containing byproducts, respectively.

On the other hand, the decarboxylative coupling of arene- and vinyl carboxylic acids with aryl halides has been developed as an alternative method for connecting π-conjugated segments.[5] However, at least to our knowledge, this new, atom-economical coupling has never been applied to vinyl−vinyl coupling. During our recent study of decarboxylative coupling of organic acids under transition-metal catalysis,[6] it has been revealed that cinnamic acids such as ferulic acids efficiently undergo the coupling with β-bromostyrenes under palladium catalysis accompanied

---

(1) Selected reviews: (a) Barnard, J. H.; Collings, J. C.; Whiting, A.; Przyborski, S. A.; Marder, T. B. *Chem.*—*Eur. J.* **2009**, *15*, 11430. (b) Thirsk, C.; Whiting, A. *J. Chem. Soc., Perkin Trans. 1* **2002**, 999. (c) Rychnovsky, S. D.; Rogers, B. N.; Richardson, T. I. *Acc. Chem. Res.* **1998**, *31*, 9. (d) Rychnovsky, S. D. *Chem. Rev.* **1995**, *95*, 2021.

(2) For recent example, see: (a) Shimizu, M.; Tatsumi, H.; Mochida, K.; Shimono, K.; Hiyama, T. *Chem. Asian J.* **2009**, *4*, 1289. (b) Lawrentz, U.; Grahn, W.; Lukaszuk, K.; Klein, C.; Wortmann, R.; Feldner, A.; Scherer, D. *Chem.*—*Eur. J.* **2002**, *8*, 1573. (c) Suzuki, T.; Higuchi, H.; Ohkita, M.; Tsuji, T. *Chem. Commun.* **2001**, 1574. (d) Kim, J.-H.; Noh, S.; Kim, K.; Lim, S.-T.; Shin, D.-M. *Synth. Met.* **2001**, *117*, 227. (e) Hünig, S.; Kemmer, M.; Wenner, H.; Barbosa, F.; Gescheidt, G.; Perepichka, I. F.; Bäuerle, P.; Emge, A.; Peters, K. *Chem.*—*Eur. J.* **2000**, *6*, 2618.

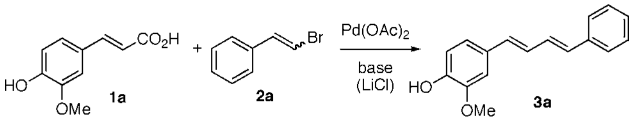
(3) (a) Davis, R.; Kumar, N. S. S.; Abraham, S.; Suresh, C. H.; Rath, N. P.; Tamaoki, N.; Das, S. *J. Phys. Chem. C* **2008**, *112*, 2137. (b) Sonoda, Y.; Goto, M.; Tsuzuki, S.; Tamaoki, N. *J. Phys. Chem. A* **2007**, *111*, 13441. (c) Sonoda, Y.; Goto, M.; Tsuzuki, S.; Tamaoki, N. *J. Phys. Chem. A* **2006**, *110*, 13379. (d) Abraham, S.; Mallia, V. A.; Ratheesh, V.; Tamaoki, N.; Das, S. *J. Am. Chem. Soc.* **2006**, *128*, 7692. (e) Lightfoot, A. P.; Twiddle, S. J. R.; Whiting, A. *Org. Biomol. Chem.* **2005**, *3*, 3167. (f) Denmark, S. E.; Tymonko, S. A. *J. Am. Chem. Soc.* **2005**, *127*, 8004. (g) Davis, R.; Mallia, V. A.; Das, S.; Tamaoki, N. *Adv. Funct. Mater.* **2004**, *14*, 743. (h) Davis, R.; Abraham, S.; Rath, N. P.; Das, S. *New J. Chem.* **2004**, *28*, 1368. (i) Sonoda, Y.; Kawanishi, Y.; Ikeda, T.; Goto, M.; Hayashi, S.; Yoshida, Y.; Tanigaki, N.; Yase, K. *J. Phys. Chem. B* **2003**, *107*, 3376. (j) Davis, R.; Mallia, V. A.; Das, S. *Chem. Mater.* **2003**, *15*, 1057. (k) Bartkowiak, W.; Zalesny, R.; Niewodniczanski, W.; Leszczynski, J. *J. Phys. Chem. A* **2001**, *105*, 10702. (l) Locknar, S. A.; Peteanu, L. A.; Shuai, Z. *J. Phys. Chem. A* **1999**, *103*, 2197. (m) Andraud, C.; Zabulon, T.; Collet, A.; Zyss, *J. Chem. Phys.* **1999**, *245*, 243. (n) Crousse, B.; Alami, M.; Linstrumelle, G. *Tetrahedron Lett.* **1997**, *38*, 5297. (o) Cheng, L.-T.; Tam, W.; Marder, S. R.; Stiegman, A. E.; Rikken, G.; Spangler, C. W. *J. Phys. Chem.* **1991**, *95*, 10643. (p) Allen, M. T.; Whitten, D. G. *Chem. Rev.* **1989**, *89*, 1691.

10.1021/ol9027896

by decarboxylation to form the corresponding 1,4-diaryl-1,3-butadiene derivatives. Ferulic acid and related compounds are widely present in plants and are readily available from biomass as promising vinyl building blocks for high-volume manufacturing.[7] β-Bromostyrenes can also be easily prepared by decarboxylative bromination[8] of cinnamic acids or other simple methods. Therefore, the coupling of these substrates appears to undoubtedly be a useful method for butadiene synthesis. The related 1,6-diaryl-1,3,5-hexatriene synthesis using a dienyl bromide or -carboxylic acid has also been achieved. These new findings are described herein.

In an initial attempt, ferulic acid (**1a**) (0.48 mmol) was treated with β-bromostyrene (**2a**) (E:Z = 6.5:1, 0.4 mmol) in the presence of Pd(OAc)$_2$ (0.02 mmol) and LiOAc (0.8 mmol) as catalyst and base, respectively, in DMF (2.5 mL) at 120 °C for 6 h under N$_2$. As a result, the decarboxylative coupling effectively proceeded to afford (1E,3E)-1-(4-hydroxy-3-methoxyphenyl)-4-phenyl-1,3-butadiene (**3a**) in 84% yield (entry 1 in Table 1). No other geometrical isomers were detected by GC-MS and NMR in the crude reaction mixture. Decreasing the amount of LiOAc to 0.48 mmol slightly reduced the product yield (entry 2). It was confirmed that the reaction did not proceed at all without the base (entry 3). Other bases such as NaOAc, KOAc, Li$_2$CO$_3$, and NaHCO$_3$ were found to be less effective than LiOAc (entries 4−7). In DMAc and DMSO, the yield of **3a** was somewhat decreased while **3a** could not be obtained at all in *o*-xylene (entries 8−10). Unexpectedly, the addition of LiCl (0.6 mmol) significantly improved the reaction efficiency. Thus, the product yield was enhanced up to 94% (entry 11). One of the possible roles of added LiCl is to provide chloride anions as ligand to prevent the deactivation of Pd(0) to metallic species.[9] Under these conditions, the amount of Pd(OAc)$_2$ could be reduced to 3 mol %, keeping the high reaction efficiency (entry 12).

Table 1. Reaction of Ferulic Acid (**1a**) with β-Bromostyrene (**2a**)[a]

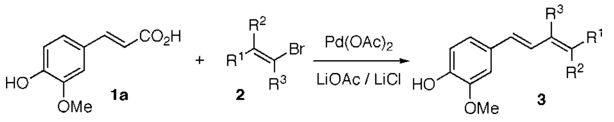


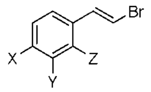
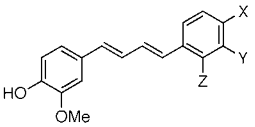
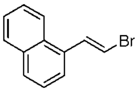
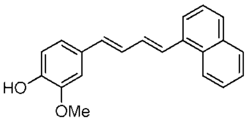
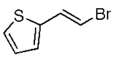
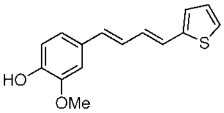
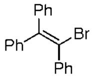
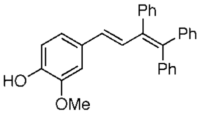
entry	base (mmol)	LiCl[b]	solvent	time (h)	% yield of 3a[c]
1	LiOAc (0.8)	−	DMF	6	84
2	LiOAc (0.48)	−	DMF	4	75
3	−	−	DMF	8	0
4	NaOAc (0.8)	−	DMF	6	61
5	KOAc (0.8)	−	DMF	8	40
6	Li$_2$CO$_3$ (0.8)	−	DMF	6	15
7	NaHCO$_3$ (0.8)	−	DMF	6	40
8	LiOAc (0.8)	−	DMAc	6	55
9	LiOAc (0.8)	−	DMSO	8	69
10	LiOAc (0.8)	−	o-xylene	8	0
11	LiOAc (0.8)	+	DMF	6	94
12[d]	LiOAc (0.8)	+	DMF	6	98 (81)

[a] Reaction conditions: [**1a**]/[**2a**]/[Pd(OAc)$_2$]/[LiCl] = 0.48:0.4:0.02:0.6 (in mmol), solvent (2.5 mL) at 120 °C under N$_2$. [b] Plus sign indicates that LiCl was added. [c] GC yield based on the amount of **2a** used. Value in parentheses indicates yield after purification. [d] With Pd(OAc)$_2$ (0.012 mmol).

The reactions of **1a** using various vinyl bromides in place of **2a** were next examined. Under optimized conditions in Table 1 (entry 12), *ortho*-, *meta*-, and *para*-substituted bromostyrenes **2b**−**i** underwent the coupling with **1a** to afford the corresponding 1,4-diarylbutadienes **3b**−**i** in good yields (entries 1−8 in Table 2). In the case with a *p*-cyano substrate **2i**, its hydrodebromination occurred to some extent. By using a slightly excess amount of **2i** at 100 °C, **3i** was obtained in a satisfactory yield (entry 8). (2-Bromoethenyl)naphthalene **2j** and -thiophene

Table 2. Reaction of Ferulic Acid (**1a**) with Vinyl Bromides **2**[a]



entry	2	3; % yield[b]
		
1	**2b**: X = Me, Y = Z = H	**3b**: X = Me, Y = Z = H; 85 (72)
2	**2c**: X = Y = OMe, Z = H	**3c**: X = Y = OMe, Z = H; 75 (63)
3	**2d**: X = Y = H, Z = OMe	**3d**: X = Y = H, Z = OMe; 90 (75)
4	**2e**: X = NMe$_2$, Y = Z = H	**3e**: X = NMe$_2$, Y = Z = H; 73 (68)
5	**2f**: X = Cl, Y = Z = H	**3f**: X = Cl, Y = Z = H; 81 (75)
6	**2g**: X = F, Y = Z = H	**3g**: X = F, Y = Z = H; 78 (67)
7	**2h**: X = CF$_3$, Y = Z = H	**3h**: X = CF$_3$, Y = Z = H; 71 (63)
8[c]	**2i**: X = CN, Y = Z = H	**3i**: X = CN, Y = Z = H; 87 (81)
9	 **2j**	 **3j**; 76 (70)
10	 **2k**	 **3k**; 73 (61)
11	 **2l**	 **3l**; 24
12[d]	**2l**	**3l**; 99 (82)

[a] Reaction conditions: [**1a**]/[**2**]/[Pd(OAc)$_2$]/[LiOAc]/[LiCl] = 0.48:0.4:0.012:0.8:0.6 (in mmol), DMF (2.5 mL) at 120 °C for 6 h under N$_2$. [b] GC yield. Value in parentheses indicates yield after purification. [c] With **1a** (0.4 mmol) and **2** (0.6 mmol) at 100 °C. [d] PPh$_3$ (0.012 mmol) was added.

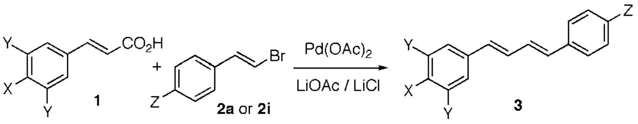
---

(4) Selected reviews: (a) Negishi, E.-I.; Huang, Z.; Wang, G.; Mohan, S.; Wang, C.; Hattori, H. *Acc. Chem. Res.* **2008**, *41*, 1474. (b) Satoh, T.; Tsurugi, H.; Miura, M. *Chem. Rec.* **2008**, *8*, 326. (c) Vasil'ev, A. A.; Serebryakov, E. P. *Russ. Chem. Rev.* **2001**, *70*, 735.

2k also reacted with **1a** under the standard conditions to form dienes **3j** and **3k**, respectively (entries 9 and 10). A sterically hindered bromide, 1-bromo-1,2,2-triphenylethene (**2l**), was found to be less reactive than β-bromostyrenes under similar conditions (entry 11). In this case, the addition of PPh_3 (0.012 mmol) effectively promoted the reaction. Thus, under the modified conditions, (1*E*,3*E*)-4-(4-hydroxy-3-methoxyphenyl)-1,1,2-triphenyl-1,3-butadiene (**3l**) was obtained almost quantitatively (entry 12).

Table 3 summarizes the results for the couplings of several substituted cinnamic acids **1b**−**e** with **2a** or **2i**. Sinapinic acid (**1b**) and coumaric acid (**1c**), which are also present in plants as well as ferulic acid, underwent the decarboxylative coupling with **2a** to produce dienes **3m** and **3n** (entries 1 and 2). In contrast, treatment of *p*-(dimethylamino)cinnamic acid (**1d**) with **2a** under similar conditions gave only a trace amount of expected product **3o** (entry 3). Interestingly, the yield of **3o** was significantly improved by the addition of AgOAc (0.6 mmol) (entry 4). AgOAc seems to promote the decarboxylation of less reactive **1d**.[10] In the presence of the silver salt, *p*-methoxycinnamic acid (**1e**) also reacted with **2a** to form diene **3p** (entry 5). The reactions of **1c** and **1d** with **2i** proceeded smoothly to form "donor−acceptor-substituted diphenylbutadienes", **3q** and **3r** (entries 6 and 7), which have attracted much attention for their unique optical properties.[3a,c,g,h,j−m,o]

Table 3. Reaction of Cinnamic Acids **1** with **2a** or **2i**[a]



entry	1	X	Y	2	Z	3; % yield[b]
1	**1b**	OH	OMe	**2a**	H	**3m**; 94 (79)
2	**1c**	OH	H	**2a**	H	**3n**; 63 (63)
3	**1d**	NMe_2	H	**2a**	H	**3o**; tr
4[c]	**1d**	NMe_2	H	**2a**	H	**3o**; 43 (43)
5[c]	**1e**	OMe	H	**2a**	H	**3p**; (53)
6[d]	**1c**	OH	H	**2i**	CN	**3q**; 80 (75)
7[e]	**1d**	NMe_2	H	**2i**	CN	**3r**; 59 (58)

[a] Reaction conditions: [**1**]/[**2**]/[Pd(OAc)$_2$]/[LiOAc]/[LiCl] = 0.48:0.4:0.012:0.8:0.6 (in mmol), DMF (2.5 mL) at 120 °C for 6 h under N_2. [b] GC yield. Value in parentheses indicates yield after purification. [c] AgOAc (0.6 mmol) was added. [d] With **1a** (0.4 mmol) and **2** (0.6 mmol). [e] [**1**]/[**2**]/[Pd(OAc)$_2$]/[LiOAc]/[LiCl]/[AgOAc] = 0.2:0.3:0.006:0.4:0.3:0.3 (in mmol), in DMF (1.5 mL).

Some of diarylbutadienes obtained above showed solid-state fluorescence in a range of 400−500 nm (see the Supporting Information). Notably, **3h** exhibited a relatively strong emission compared to a typical emitter, tris(8-hydroxyquinolino)aluminum (Alq$_3$), by a factor of 4.5 (λ_{emis} 450, 472 nm, A versus B in Figure 1).

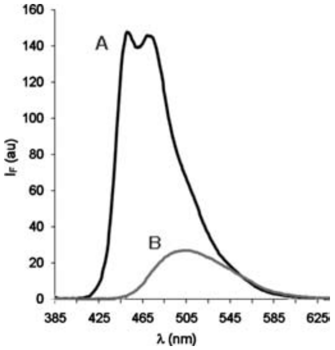


Figure 1. Fluorescence spectra of **3h** (A) and Alq$_3$ (B) in the solid-state upon excitation at 380 nm.

1,6-Diaryl-1,3,5-hexatriene synthesis could be achieved by the present decarboxylative coupling. Thus, treatment of ferulic acid (**1a**) (0.48 mmol) with 1-bromo-4-phenyl-1,3-butadiene (**2m**) (0.4 mmol) under the standard conditions gave 1-(4-hydroxy-3-methoxyphenyl)-6-phenyl-1,3,5-hexatriene (**4a**) in 68% yield (entry 1 in Table 4). As in the case using a less reactive bromide **2l**, the reaction with **2m** was also promoted by the addition of PPh_3 (0.012 mmol) to improve the yield of **4a** up to 74% (entry 2). Under the conditions with PPh_3, **1b** and **1c** also reacted with **2m** to produce trienes **4b** and **4c**, respectively (entries 3 and 4).

---

(5) Selected reviews: (a) Goossen, L. J.; Rodriguez, N.; Goossen, K. *Angew. Chem., Int. Ed.* **2008**, *47*, 3100. (b) Baudoin, O. *Angew. Chem., Int. Ed.* **2007**, *46*, 1373. For reviews concerning coupling via C−C bond cleavage, see: (c) Yorimitsu, H.; Oshima, K. *Bull. Chem. Soc. Jpn.* **2009**, *82*, 778. (d) Park, Y. J.; Park, J.-W.; Jun, C.-H. *Acc. Chem. Res.* **2008**, *41*, 222. (e) Catellani, M.; Motti, E.; Della Ca', N. *Acc. Chem. Res.* **2008**, *41*, 1512. (f) Nakao, Y.; Hiyama, T. *Pure Appl. Chem.* **2008**, *80*, 1097. (g) Tobisu, M.; Chatani, N. *Chem. Soc. Rev.* **2008**, *37*, 300. (h) Satoh, T.; Miura, M. *Top Organomet. Chem.* **2007**, *24*, 61. (i) Murakami, M.; Makino, M.; Ashida, S.; Matsuda, T. *Bull. Chem. Soc. Jpn.* **2006**, *79*, 1315. (j) Kondo, T.; Mitsudo, T. *Chem. Lett.* **2005**, *34*, 1462. (k) Jun, C.-H. *Chem. Soc. Rev.* **2004**, *33*, 610. (l) Nishimura, T.; Uemura, S. *Synlett* **2004**, 201. (m) van der Boom, M. E.; Milstein, D. *Chem. Rev.* **2003**, *103*, 1759. (n) Perthuisot, C.; Edelbach, B. L.; Zubris, D. L.; Simhai, N.; Iverson, C. N.; Muller, C.; Satoh, T.; Jones, W. D. *J. Mol. Catal. A: Chem.* **2002**, *189*, 157.

(6) (a) Yamashita, M.; Horiguchi, H.; Hirano, K.; Satoh, T.; Miura, M. *J. Org. Chem.* **2009**, *74*, 7481. (b) Shimizu, M.; Hirano, K.; Satoh, T.; Miura, M. *J. Org. Chem.* **2009**, *74*, 3478. (c) Miyasaka, M.; Hirano, K.; Satoh, T.; Miura, M. *Adv. Synth. Catal.* **2009**, *351*, 2683. (d) Yamashita, M.; Hirano, K.; Satoh, T.; Miura, M. *Org. Lett.* **2009**, *11*, 2337. (e) Miyasaka, M.; Fukushima, A.; Satoh, T.; Hirano, K.; Miura, M. *Chem.—Eur. J.* **2009**, *15*, 3674. (f) Maehara, A.; Tsurugi, H.; Satoh, T.; Miura, M. *Org. Lett.* **2008**, *10*, 1159. (g) Nakano, M.; Tsurugi, H.; Satoh, T.; Miura, M. *Org. Lett.* **2008**, *10*, 1851. (h) Ueura, K.; Satoh, T.; Miura, M. *J. Org. Chem.* **2007**, *72*, 5362.

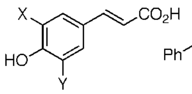
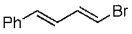
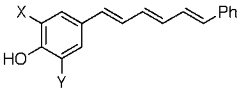
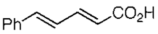
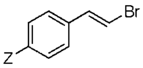
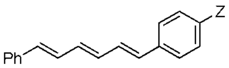
(7) (a) Tsujiyama, S.; Ueno, M. *Biosci. Biotechnol. Biochem.* **2008**, *72*, 212. (b) Nomura, E.; Hosoda, A.; Mori, H.; Taniguchi, H. *Green Chem.* **2005**, *7*, 863. (c) Nomura, E.; Kashiwada, A.; Hosoda, A.; Nakamura, K.; Morishita, H.; Tsuno, T.; Taniguchi, H. *Bioorg. Med. Chem.* **2003**, *11*, 3807.

(8) (a) Das, J. P.; Roy, S. *J. Org. Chem.* **2002**, *67*, 7861. (b) Kuang, C.; Yang, Q.; Senboku, H.; Tokuda, M. *Synlett* **2000**, 1439. (c) Naskar, D.; Roy, S. *Tetrahedron* **2000**, *56*, 1369. (d) Chowdhury, S.; Roy, S. *J. Org. Chem.* **1997**, *62*, 199.

(9) (a) Amatore, C.; Jutand, A.; Suarez, A. *J. Am. Chem. Soc.* **1993**, *115*, 9531. (b) Amatore, C.; Azzabi, M.; Jutand, A. *J. Am. Chem. Soc.* **1991**, *113*, 8375.

(10) (a) Lu, P.; Sanchez, C.; Cornella, J.; Larrosa, I. *Org. Lett.* **2009**, *11*, 5710. (b) Goossen, L. J.; Linder, C.; Rodriguez, N.; Lange, P. P.; Fromm, A. *Chem. Commun.* **2009**, 7173. (c) Cornella, J.; Sanchez, C.; Banawa, D.; Larrosa, I. *Chem. Commun.* **2009**, 7176.

Table 4. Synthesis of 1,6-Diaryl-1,3,5-hexatrienes **4**[a]

entry	substrates		**4**; % yield[b]
			
1	**1a**: X = OMe, Y = H	**2m**	**4a**: X = OMe, Y = H; 68 (55)
2[c]	**1a**: X = OMe, Y = H		**4a**: X = OMe, Y = H; 74 (64)
3[c]	**1b**: X = Y = OMe		**4b**: X = Y = OMe; 75 (64)
4[c]	**1c**: X = Y = H		**4c**: X = Y = H; 66 (61)
			
5	**1f**	**2a**: Z = H	**4d**: Z = H; 10
6[d]		**2a**: Z = H	**4d**: Z = H; 62 (62)
7[d]		**2f**: Z = Cl	**4e**: Z = Cl; 68 (66)
8[d]		**2h**: Z = CF_3	**4f**: Z = CF_3; (61)

[a] Reaction conditions: [**1**]/[**2**]/[$Pd(OAc)_2$]/[LiOAc]/[LiCl] = 0.48:0.4:0.012:0.8:0.6 (in mmol), DMF (2.5 mL) at 120 °C for 6 h under N_2. [b] GC yield. Value in parentheses indicates yield after purification. [c] PPh_3 (0.012 mmol) was added. [d] With AgOAc (0.8 mmol) at 100 °C.

Meanwhile, 5-phenyl-2,4-pentadienoic acid (**1f**) also underwent the decarboxylative coupling with **2a**, **2f**, and **2h** to afford the corresponding 1,6-diaryl-1,3,5-hexatrienes **4d**-**f** (entries 5−8). In these cases, the addition of AgOAc was essential to conduct the reactions efficiently (entry 6 vs 5), as in the reactions using **1d** and **1e** (entries 4, 5, and 7 in Table 3).

In summary, we have demonstrated that the palladium-catalyzed coupling of cinnamic acids with β-bromostyrenes proceeds efficiently via decarboxylation to give the corresponding 1,4-diaryl-1,3-butadiene derivatives. The coupling is also applicable to 1,6-diaryl-1,3,5-hexatriene synthesis. Such polyenes are of interest due to their optical properties.

Acknowledgment. This work was partly supported by Grants-in-Aid from the Ministry of Education, Culture, Sports, Science and Technology, Japan and the Kurata Memorial Hitachi Science and Technology Foundation.

Supporting Information Available: Standard experimental procedure and characterization data of products. This material is available free of charge via the Internet at http://pubs.acs.org.

OL9027896