Cross-coupling Reaction of Allylic and Benzylic Carbonates with Organo[2-(hydroxymethyl)phenyl]dimethylsilanes

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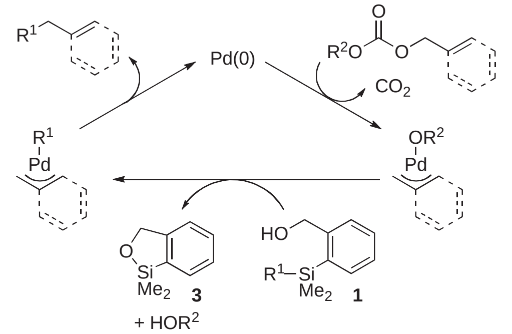
The title reaction is found to proceed in the presence of a palladium catalyst and in the absence of any activator. Various functional groups are tolerated to give a diverse range of 1,4-diene and diarylmethane products, which are ubiquitous units of natural products and pharmaceuticals.

The structures of non-conjugated 1,4-diene, 3-arylpropene, and diarylmethane are found in many natural products and pharmaceuticals, and are often constructed by the cross-coupling reactions of alkenyl- or arylmetallic reagents with allyl or benzyl electrophiles.[1] Whereas silicon-based approach[2] toward these frameworks is apparently a promising alternative to the conventional ones[1] in view of high stability and non-toxicity associated with organosilicon reagents, only a few protocol has been available to date using moisture and acid/base sensitive organo(fluoro)silanes[3] and organo(trialkoxy)silanes.[4]

We have recently disclosed that organo[2-(hydroxymethyl)phenyl]dimethylsilanes (**1**) behave as a new class of silane coupling reagents for the palladium-catalyzed cross-coupling reaction.[5] The reagents allow chemically stable tetraorganosilicon compounds to participate in the cross-coupling chemistry under fluoride-free conditions for the first time with excellent chemoselectivities. The proximal hydroxy group is supposed to be converted to an alkoxide upon treatment with a mild base, such as K_2CO_3, and coordinate to the nearby silicon atom to produce a requisite five-membered penta-coordinated silicate species. Given the importance of the aforementioned transformations, we hypothesized that a palladium alkoxide species generated by oxidative addition of allylic and benzylic carbonates **2** to Pd^0 would act as a base to allow the cross-coupling reaction of our silicon reagents with these carbonate esters under neutral conditions (Scheme 1).[6] This has turned out to be the case as reported herein.

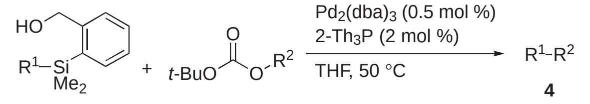


R^1= (*E*)-HexCH=CH (**1a**)
(*E*)-NC$(CH_2)_3$CH=CH (**1b**)
(*E*)-TBDMSO$(CH_2)_3$CH=CH (**1c**)
(*E*)-Cl$(CH_2)_3$CH=CH (**1d**)
(*E*)-PhthNCH$_2$CH=CH (**1e**)
(*E*)-HOCMe$_2$CH=CH (**1f**)
(*E*)-PhCH=CH (**1g**)
(*Z*)-PhCH=CH (**1h**)
H_2C=CPh (**1i**)
(*E*)-PrCH=CPr (**1j**)
Ph (**1k**)
4-MeO–C_6H_4 (**1l**)

Scheme 1.

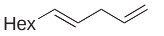
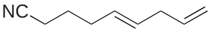
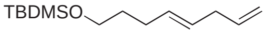
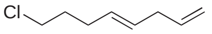
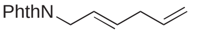
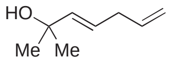
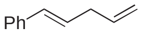
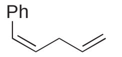
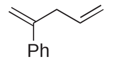
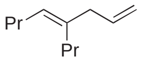
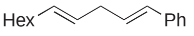
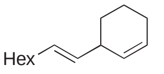
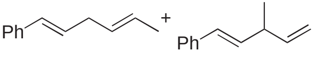
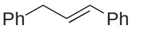
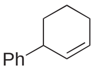
We first examined the reaction of (*E*)-[2-(hydroxymethyl)phenyl]dimethyl(1-octenyl)silane (**1a**: 1.0 mmol) with allyl *tert*-butyl carbonate (**2a**: 1.0 mmol) in the presence of 0.5 mol % of $Pd_2(dba)_3$ and 2.0 mol % of $(2\text{-thienyl})_3P$ (2-Th_3P) as a ligand[7] in THF at 50 °C to obtain (*E*)-1,4-undecadiene (**4aa**) in 85% yield after 2 h (Entry 1 of Table 1).[8] Excellent chemoselectivity was observed with (*E*)-alkenylsilanes having a func-

Table 1. Cross-coupling reaction of organo[2-(hydroxymethyl)phenyl]dimethylsilanes (**1**) with allylic *tert*-butyl carbonates **2**



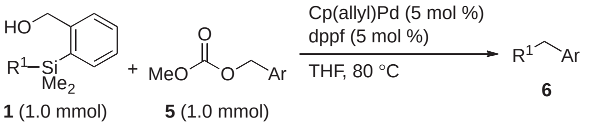
1 (1.0 mmol) **2** (1.0 mmol)

R^2 = allyl (**2a**); (*E*)-cinnamyl (**2b**); 2-cyclohexenyl (**2c**); crotyl (methyl carbonate, **2d**)

Entry	1	2	Time/h	Product	Yield/%[a]
1	**1a**	**2a**	2		85 (**4aa**)
2	**1b**	**2a**	4		85 (**4ba**)
3	**1c**	**2a**	2		72 (**4ca**)
4	**1d**	**2a**	2		74 (**4da**)
5	**1e**	**2a**	3		85 (**4ea**)
6	**1f**	**2a**	4		53 (**4fa**)
7	**1g**	**2a**	2		91 (**4ga**)
8	**1h**	**2a**	2		92 (**4ha**)
9	**1i**	**2a**	3		81 (**4ia**)
10	**1j**	**2a**	24		78 (**4ja**)
11	**1a**	**2b**	3		93 (**4ab**)[b]
12	**1a**	**2c**	4		92 (**4ac**)
13	**1g**	**2d**	7		68 (**4gd**)[c]
14[d]	**1k**	**2b**	6		73 (**4kb**)
15[d]	**1k**	**2c**	6		75 (**4kc**)

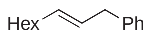
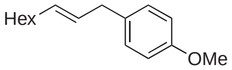
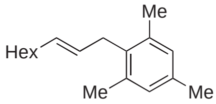
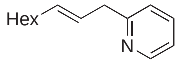
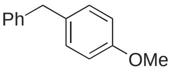
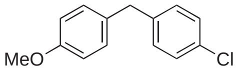
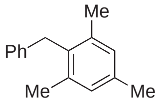
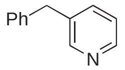
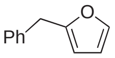
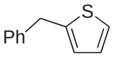
[a]Isolated yields based on **1**. [b]Cyclic silyl ether **3** was also isolated in 80% yield on a 10 mmol scale. [c]The ratio of isomers was determined to be 73:27 by ^{1}H NMR. [d]The reaction was carried out at 70 °C using CuOAc (50 μmol) as a co-catalyst.

Table 2. Cross-coupling reaction of organo[2-(hydroxymethyl)phenyl]dimethylsilanes (**1**) with arylmethyl methyl carbonates **5**



1 (1.0 mmol) **5** (1.0 mmol) **6**

Ar = Ph (**5a**); 4-MeO–$\mathrm{C_6H_4}$ (**5b**); 4-Cl–$\mathrm{C_6H_4}$ (**5c**); 2,4,6-$\mathrm{Me_3}$–$\mathrm{C_6H_2}$ (**5d**); 2-pyridyl (**5e**); 3-pyridyl (**5f**); 2-furyl (**5g**); 2-thienyl (**5h**)

Entry	1	5	Time/h	Product	Yield/%[a]
1	**1a**	**5a**	18		87 (**6aa**)
2	**1a**	**5b**	10		89 (**6ab**)
3	**1a**	**5d**	10		86 (**6ad**)
4	**1a**	**5e**	40		75 (**6ae**)
5[b]	**1k**	**5b**	8		92 (**6kb**)
6[b]	**1l**	**5c**	13		70 (**6lc**)
7[b]	**1k**	**5d**	8		87 (**6kd**)
8[b]	**1k**	**5f**	8		78 (**6kf**)
9[b]	**1k**	**5g**	9		75 (**6kg**)
10[b]	**1k**	**5h**	8		71 (**6kh**)

[a]Isolated yields. [b]The reaction was carried out using Cu(OAc) (50 µmol) as a co-catalyst.

tional group, such as cyano, siloxy, chloro, or phthalimide, giving various 1,4-dienes in good yields (Entries 2–5). Free hydroxy, which serves as a nucleophile in π-allylpalladium chemistry, was also compatible (Entry 6). (*E*)- and (*Z*)-β-Styryl-, α-phenylvinyl-, and (*E*)-4-octenylsilanes participated in the reaction with **2a** in good yields with perfect regio- and stereospecificities (Entries 7–10). (*E*)-Cinnamyl (**2b**) carbonate similarly reacted with **1a** to give linear (*E*)-1-phenyl-1,4-undecadiene (**4ab**) in 93% yield irrespective of a reaction scale (1 and 10 mmol) (Entry 11). The reaction on a 10 mmol scale allowed isolation of cyclic silyl ether **3**, a silicon residue, in 80% yield, which is reusable for the synthesis of the silane reagents.[5] *tert*-Butyl 2-cyclohexenyl carbonate (**2c**) readily participated in the reaction to give the corresponding coupling product in 92% yield (Entry 12), whereas crotyl methyl carbonate (**2d**) gave a mixture of linear and branched products (Entry 13). Phenylsilane **1k** underwent the allyl coupling reaction with **2b** and **2c** by using a 5.0 mol % of $\mathrm{Cu^I}$ co-catalyst in a THF solvent at 70 °C (Entries 14 and 15).

We then turned our attention to the cross-coupling reaction with benzylic carbonate. Recently, Kuwano and Yokogi have revealed that benzylic carbonates serve as electrophiles for the cross-coupling chemistry by employing a Pd/bisphosphine system.[1a] We also surveyed several combinations of a palladium catalyst and a bisphosphine ligand and identified the combination of (η^5-cylcopentadienyl)(η^3-allyl)palladium [Cp(allyl)Pd] and 1,1′-bis(diphenylphosphino)ferrocene (dppf) was optimum. Thus, the reaction of (*E*)-1-octenylsilane **1a** with benzyl methyl carbonate (**5a**) in the presence of 5 mol % of Cp(allyl)Pd and dppf in THF at 80 °C for 18 h gave (*E*)-1-phenyl-2-nonene (**6aa**) in 87% yield (Entry 1 of Table 2). To our knowledge, this is the first example of the silicon-based cross-coupling reaction with a benzylic electrophile. Under the identical conditions, 4-methoxyphenyl (**5b**), 2,4,6-trimethylphenyl (**5d**), and 2-pyridyl (**5e**) carbonate also cross-coupled with **1a** to give various (*E*)-1-aryl-2-nonenes in good yields (Entries 2–4). The aryl-benzylic coupling reactions with CuOAc as a $\mathrm{Cu^I}$ co-catalyst also met with success. Arylsilanes cross-coupled successfully with a range of arylmethyl carbonates including heteroarenes to allow the silicon-based access to various diarylmethanes (Entries 5–10).[2]

In summary, we have demonstrated that organo[2-(hydroxymethyl)phenyl]dimethylsilanes undergo the cross-coupling reaction with allylic and benzylic carbonates to give a variety of 1,4-dienes, 3-arylpropenes, and diarylmethanes in a highly chemoselective manner. The use of readily accessible, highly stable, and recyclable tetraorganosilicon compounds under mild conditions free of an activator is definitely an attractive feature that may replace the conventional protocols. Other catalytic and non-catalytic transformations of the silane reagents are currently under investigations in our laboratory.

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References and Notes

1 For selected recent examples, see: a) R. Kuwano, M. Yokogi, *Org. Lett.* **2005**, *7*, 945. b) M. J. Schnermann, D. L. Boger, *J. Am. Chem. Soc.* **2005**, *127*, 15704. c) G. W. Kabalka, M. Al-Masum, *Org. Lett.* **2006**, *8*, 11. d) K. A. Keaton, A. J. Phillips, *J. Am. Chem. Soc.* **2006**, *128*, 408.

2 For synthesis of diarylmethanes using (2-pyridyl)silylmethylstannane as a coupling partner, see: K. Itami, M. Mineno, T. Kamei, J. Yoshida, *Org. Lett.* **2002**, *4*, 3635.

3 a) J. Yoshida, K. Tamao, H. Yamamoto, T. Kakui, T. Uchida, M. Kumada, *Organometallics* **1982**, *1*, 542. b) H. Matsuhashi, S. Asai, K. Hirabayashi, Y. Hatanaka, A. Mori, T. Hiyama, *Bull. Chem. Soc. Jpn.* **1997**, *70*, 1943. c) M.-R. Brescia, P. DeShong, *J. Org. Chem.* **1998**, *63*, 3156.

4 a) R. Correia, P. DeShong, *J. Org. Chem.* **2001**, *66*, 7159. b) G. W. Kabalka, G. Dong, B. Venkataiah, C. Chen, *J. Org. Chem.* **2005**, *70*, 9207.

5 Y. Nakao, H. Imanaka, A. K. Sahoo, A. Yada, T. Hiyama, *J. Am. Chem. Soc.* **2005**, *127*, 6952.

6 a) F. Guibe, Y. S. M'leux, *Tetrahedron Lett.* **1981**, *22*, 3591. b) J. Tsuji, I. Shimizu, I. Minami, Y. Ohashi, T. Sugiura, K. Takahashi, *J. Org. Chem.* **1985**, *50*, 1523.

7 The reaction using $\mathrm{(2\text{-}furyl)_3P}$ as a ligand resulted in a slightly lower yield.

8 In all cases in this study, O-allylation of **1** was observed $<5\%$, if any.

9 Supporting Information is available electronically on the CSJ-Journal Web site; http://www.csj.jp/journals/chem-lett/.

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