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$B(C_6F_5)_3$-Catalyzed Allylation of Propargyl Acetates with Allylsilanes

Todd Schwier, Michael Rubin, and Vladimir Gevorgyan*

Department of Chemistry, University of Illinois at Chicago, 845 West Taylor Street, Chicago, Illinois 60607-7061

vlad@uic.edu

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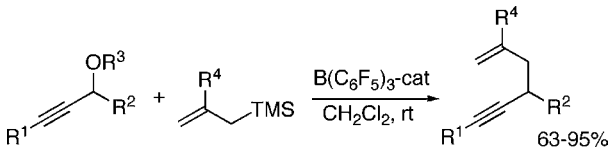
ABSTRACT



An efficient method for the $B(C_6F_5)_3$-catalyzed allylation of secondary propargylic alcohol derivatives with allylsilanes has been developed. This method allows for the facile synthesis of a variety of 1,5-enynes in good to high yields with a number of functionalities, such as nitro, chloro, ester, and boronic ester, being tolerated under the reaction conditions.

Lewis acid-induced coupling of propargyl halides, alcohols, and their derivatives with allylsilanes is an important transformation, as it provides a direct approach to synthetically valuable 1,5-enynes.[1] Reactions of this type that are stoichiometric in Lewis acids have been developed by Müller and Green, on propargylic acetates,[2] and Schreiber, on propargylic ethers.[3] Such methods, however, are limited to the employment of substrates possessing strong cation-stabilizing groups: (arene)$Cr(CO)_3$ in the former case and dicobalt complexes in the latter two. Catalytic Lewis acid procedures are limited to Mayr's coupling of allylsilanes with propargylic halides,[4] and single examples by Hayashi on a propargylic ether[5] and by Saito on a mixed benzylic-propargylic silyl ether (R^2 = Ar).[6] Very recently, Toste described an efficient coupling of allylsilane and propargylic alcohols in the presence of catalytic amounts of a Re catalyst.[7] The reaction is high yielding when applied to highly stabilized substrates possessing both an alkynyl and aryl substituent at the reactive center (R^2 = Ar). However, secondary propargylic alcohol with Me at R^2 gives a low yield (Scheme 1).[8] Herein, we wish to report a highly efficient method for coupling allylsilanes with propargylic acetates in the presence of a catalytic amount of $B(C_6F_5)_3$.[9] A wide range of secondary propargylic acetates possessing methyl, aryl, or alkynyl substituents at R^2 can effectively be employed under these reaction conditions.

We have recently developed a highly efficient $B(C_6F_5)_3$-catalyzed coupling of allylsilanes with benzylic alcohols and their derivatives.[10] Naturally, we intended to extend this

(1) (a) Nishida, M.; Adachi, N.; Onozuka, K.; Matsumura, H.; Mori, M. *J. Org. Chem.* **1998**, *63*, 9158. (b) Corey, E. J.; Katzenellenbogen, J. A.; Gilman, N. W.; Roman, S. A.; Erickson, B. W. *J. Am. Chem. Soc.* **1968**, *90*, 5618. (c) Corey, E. J.; Achiwa, K. *Tetrahedron Lett.* **1970**, *26*, 2245. (d) Rhode, O.; Hoffmann, H. M. R. *Tetrahedron* **2000**, *56*, 6479.

(2) (a) Müller, T. J. J.; Netz, A. *Tetrahedron Lett.* **1999**, *40*, 3145. (b) Green, J. R. *Chem. Commun.* **1998**, *16*, 1751.

(3) Schreiber, S. L.; Sammakia, T.; Crowe, W. E. *J. Am. Chem. Soc.* **1986**, *108*, 3128.

(4) Dau-Schmidt, J.-P.; Mayr, H. *Chem. Ber.* **1994**, *127*, 205.

(5) Hayashi, M.; Inubushi, A.; Mukaiyama, T. *Chem. Lett.* **1987**, 1975.

(6) Ishikawa, T.; Okano, M.; Aikawa, T.; Saito, S. *J. Org. Chem.* **2001**, *66*, 4635.

(7) Luzung, M. R.; Toste, F. D. *J. Am. Chem. Soc.* **2003**, *125*, 15760.

(8) Additionally, Saito has demonstrated the diastereoselective allylation of mixed allylpropargyl systems, in which allylation occurs at the γ-position to the propargyl moiety. See: Ishikawa, T., Aikawa, T., Mori, Y., Saito, S. *Org. Lett.* **2004**, *6*, 1369.

(9) For recent applications of $B(C_6F_5)_3$, see: (a) Chen, E. Y.-X.; Marks, T. J. *Chem. Rev.* **2000**, *100*, 1391. (b) Gevorgyan, V.; Rubin, M.; Benson, S.; Liu, J.-X.; Yamamoto, Y. *J. Org. Chem.* **2000**, *65*, 6179. (c) Gevorgyan, V.; Rubin, M.; Liu, J.-X.; Yamamoto, Y. *J. Org. Chem.* **2001**, 66, 1672. (d) Rubin, M.; Schwier, T.; Gevorgyan, V. *J. Org. Chem.* **2002**, 67, 1936. (e) Blackwell, J. M.; Sonmor, E. R.; Scoccitti, T.; Piers, W. E. *Org. Lett.* **2000**, *2*, 3921. (f) Parks, D. J.; Blackwell, J. M.; Piers, W. E. *J. Org. Chem.* **2000**, *65*, 3090. (g) Blackwell, J. M.; Piers, W. E. *Org. Lett.*, **2000**, *2*, 695. (h) Watson, I. D. G.; Yudin, A. K. *J. Org. Chem.* **2003**, *68*, 5160. (i) Chandrasekhar, S.; Reddy, C. R.; Babu, B. N.; Chandrashekar, G. *Tetrahedron Lett.* **2002**, *43*, 3801.

(10) Rubin, M.; Gevorgyan, V. *Org. Lett.* **2001**, *3*, 2705.

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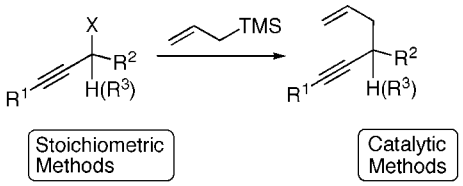
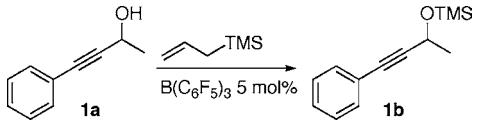
Scheme 1. Known Methods for Allylation of Propargyl Systems



Schreiber 1986:	X = OMe, R^2 = H	Hayashi 1987:	X = OMe, R^2 = Alkyl
Green 1998:	X = OAc, R^2 = Ar, Me, H	Mayr 1994:	X = Cl, $R^2 = R^3$ = Me
Müller 1999:	X = OAc, R^2 = Ar	Saito 2001:	X = OTMS, R^2 = Ar
		Toste 2003:	X = OH, R^2 = Aryl

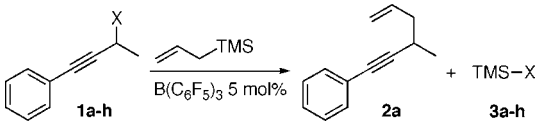
method to the analgous propargylic systems en route to 1,5-enynes. Initial experiments on allylation of propargylic alcohol **1a** in the presence of $B(C_6F_5)_3$ failed. The corresponding silyl ether, **1b** (Scheme 2), was formed instead.[11]

Scheme 2. Silyl Ether Formation via Allylsilane



Accordingly, we began searching for an appropriate leaving group, which we thought would allow for the allylation reaction (Table 1). We were pleased to find that acetate **1c** participated in the allylation reaction to give **2a** in 95% yield (entry 3). The reaction, however, was rather slow, requiring

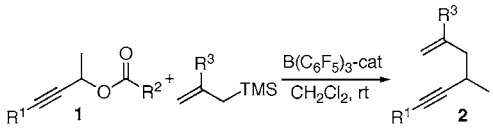
Table 1. Optimization of Leaving Group

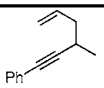
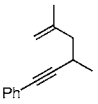
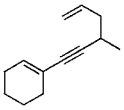
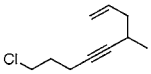
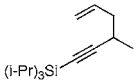
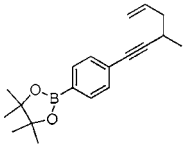
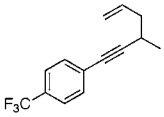
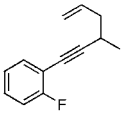
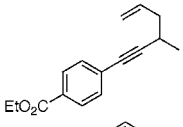
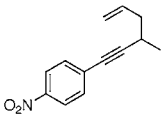
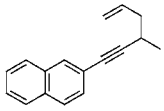
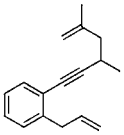
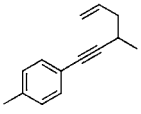


			leaving group (X)	reaction time	**2a**, yield, %
1	OH	**1a**		1 day	NR
2	OTMS	**1b**		1 day	NR
3	$OCOCH_3$	**1c**		5 days	95
4	$OCOC(CH_3)_3$	**1d**		>7 days	~70[a]
5	$OCOCF_3$	**1e**		<2 min	50
6	$OCOCCl_3$	**1f**		<5 min	30
7	$OCOCH_2Cl$	**1g**		1 h	95
8	OCO_2Ph	**1h**		1 h	80

[a] About 20% of **1d** was recovered.

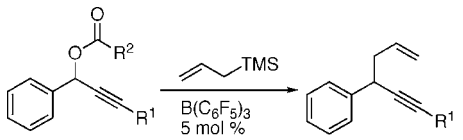
Table 2. Allylation of Secondary Propargyllic Acetates



	R^2		R^3	product **2**		yield, %[a,b]
1	CH_2Cl	**1 g**	H		**2 a**	95
2	CH_2Cl	**1 g**	Me		**2 b**	70
3	OPh	**1 i**	H		**2 c**	(63)
4	CH_2Cl	**1 j**	H		**2 d**	91
5	CH_2Cl	**1 k**	H		**2 e**	84
6	CH_2Cl	**1 l**	H		**2 f**	(70)
7	CH_2Cl	**1 m**	H		**2 g**	68
8	CH_2Cl	**1 n**	H		**2 h**	68
9	OPh	**1 o**	H	"	**2 h**	63
10	CH_2Cl	**1 p**	H		**2 i**	85
11	CH_2Cl	**1 q**	H		**2 j**	82
12	OPh	**1 r**	H		**2 k**	75
13	CH_2Cl	**1 s**	Me		**2 l**	81
14	CH_2Cl	**1 t**	H		**2 m**	76[c]

[a] Isolated yield. [b] NMR yield in parentheses. [c] 3 equiv of allylsilane was used.

Scheme 3. Allylation of Phenyl-Substituted Propargylic Acetates



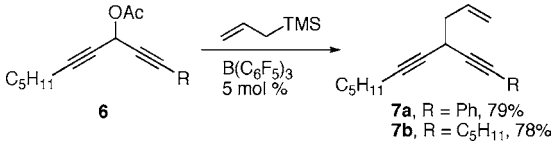
4a, R^1 = Ph, R^2 = CH_3
4b, R^1 = Pr, R^2 = CH_3
4c, R^1 = H, R^2 = CH_2Cl

5a, R^1 = Ph, 93%
5b, R^1 = Pr, 90%
5c, R^1 = H, 71%

5 days for completion. Pivalate **1d** reacted even more sluggishly, resulting in incomplete reaction, probably due to deactivation of the catalyst. In contrast, trifluoroacetate **1e** and trichloroacetate **1f** underwent the transformation almost instantaneously. In these cases, however, the reactions also lead to the formation of somewhat Lewis acidic byproducts **3e** and **3f**, causing isomerization and polymerization of the forming enynes.[12] Gratifyingly, we found that monochloroacetate **1g** and carbonate **1h** reacted smoothly under these conditions to give the desired product **2a** in high yields, with no aforementioned side processes detected. With suitable leaving groups established, we began an investigation of the scope of the $B(C_6F_5)_3$-catalyzed allylation reaction (Table 2).[13]

Chloroacetate **1g** underwent smooth allylation with allyltrimethylsilane and with methallylsilane to give **2a** and **2b** in 95 and 70% yield, respectively (entries 1 and 2).[14] Allylation of **1g** with methallylsilane gave **2b** in good yield, as well (entry 2). Reaction of carbonate **1i** produced the rather unstable unsaturated hydrocarbon **2c** in 63% NMR yield. Chloroacetates **1j** and **1k**, possessing further functionalizable moieties, were allylated in high yields, 91% and 84%, respectively (entries 4 and 5). Boronic ester-containing **1l**, a potential synthon for Suzuki coupling, was allylated in 70% yield (entry 6). Chloroacetates **1m**, **1n**, and carbonate **1o**, possesing electron-withdrawing groups at the aryl ring, were successfully allylated in good yields as well (entries 7−9). Remarkably, substrates possesing ester and nitro functionalities were also successfully employed in the reaction to give the allylated products **2i** and **2j** in high yields (entries 10 and 11). Allylation of 2-naphthyl derivative **1r** proceeded uneventfully, providing **2k** in 75% yield (entry 12). Chloroacetate **1s** smoothly reacted with methallylsilane to give **2l** 81% yield (entry 13).

Scheme 4. Allylation of Bis-propargylic Acetates



6

7a, R = Ph, 79%
7b, R = C_5H_{11}, 78%

We also examined the allylation of propargylic acetates possessing a phenyl subsituent **4** (Scheme 3). We were pleased to find that benzylic-propargylic acetates **4a**−**c** gave the desired 1,5-enynes **5a**−**c** in very high to good yields.

Likewise, bis-propargylic acetates **6** underwent smooth allylation to furnish the enediyne products **7a** and **7b** in good yield (Scheme 4). It should be noted that the allylation of all substrates (**1**, **4**, and **6**) led exclusively to formation of propargyllic products, and no traces of allenic side products were detected by GC/MS or NMR analysis of the crude reaction mixtures.[15]

In summary, we have developed an effective protocol for the allylation of secondary propargylic acetates and carbonates with allylsilanes in the presence of a catalytic amount of $B(C_6F_5)_3$. The synthesis of a number of 1,5-enynes and enediynes, possessing various functionalities, has been accomplished by virtue of this method.

Acknowledgment. The support of the Petroleum Research Fund (AC1-40691), administered by the American Chemical Society, is gratefully acknowledged.

Supporting Information Available: Experimental details. This material is available free of charge via the Internet at http://pubs.acs.org.

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(11) For use of allylsilanes as silylating agents of alcohols and carboxylic acids, see: Morita, T.; Okamoto, Y.; Sakurai, H. *Tetrahedron Lett.* **1980**, *21*, 835.

(12) Test experiments showed that **3e**, in the presence of 5 mol % $B(C_6F_5)_3$, leads to the decomposition of 1,5-enyne **2a**.

(13) Attempts on allylation of secondary acetates with alkyl groups, other than methyl, at R^2 and tertiary acetates resulted in the formation of notable to substantial amounts of elimination and oligimerization side products.

(14) All reactions were carried out with 5 mol % of $B(C_6F_5)_3$. Reactions employing lower catalyst loadings required longer reaction times or did not proceed to completion. The preparation of **2a** is representative. To a stirred solution of **1f** (1 mmol, 222 mg) and allyltrimethylsilane (1.5 mmol, 240 μL) in anhydrous CH_2Cl_2 (500 μL) was added a solution of $B(C_6F_5)_3$ (26 mg, 5 mol %) in anhydrous CH_2Cl_2 (500 μL).The mixture was stirred at room temperature, and the reaction progress was monitored by capillary GLC analysis. Once the reaction was complete (1 h for **2a**), the reaction was filtered through a short column (silica gel) and concentrated. The crude oil was purified by column chromatography (silica gel, hexane as eluent) to give 161 mg (95%) of **2a**.

(15) It has been previously shown that the reaction of highly stabilized propargyl cations (e.g., bis-arylpropargyl) with soft nucleophiles leads to the regioselective formation of allenic products. In cases where the substrates lack such strong stabilization, the propargyl compounds were formed exclusively. For the formation of allenic products, see: Müller, T. J. J. *Eur. J. Org. Chem.* **2001**, 2021.