Communication

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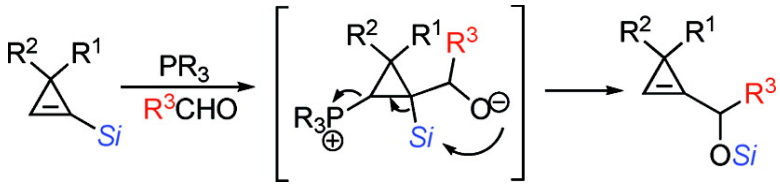

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Sila Morita−Baylis−Hillman Reaction of Cyclopropenes

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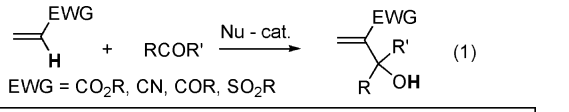
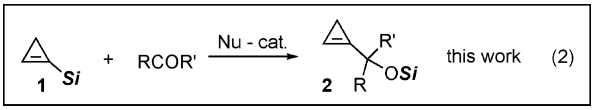
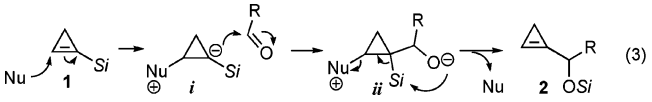
The Morita−Baylis−Hillman (MBH) reaction[1] is an attractive and powerful tool for carbon−carbon bond formation (eq 1). This protocol involves amine- or phosphine-catalyzed coupling of Michael-acceptors with carbonyl compounds or their equivalents. Herein, we report the phosphine-catalyzed sila-MBH reaction of 1-silyl-cyclopropenes **1** with carbonyl compounds, which produces 1-(silyloxymethyl)cyclopropenes **2** in good to excellent yields (eq 2).





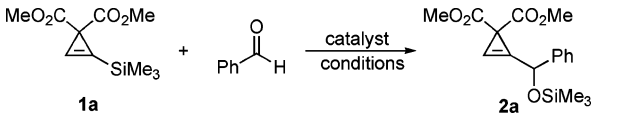
Cyclopropenes[2] are the smallest unsaturated carbocycles, possessing a highly strained[3] double bond, which readily undergoes a wide array of addition reactions.[4,5] We hypothesized that 1-silyl-substituted cyclopropenes might be suitable substrates for a sila-MBH reaction on the basis of the following reasoning. It was thought that the high reactivity of the cyclopropene double bond, together with the ability of silyl group to stabilize α-carbanion,[6] could allow for the formation of α-silylcyclopropyl anion ***i***[7] upon addition of nucleophilic catalyst[4a−d] to 1-silylcyclopropene **1** (eq 3). If long-lived, intermediate ***i*** may undergo an addition to carbonyl group to produce alkoxide ***ii***, which was reasoned to be an ideal substrate for a subsequent 1,3-Brook rearrangement[8]/elimination cascade to furnish 1-(silyloxymethyl)cyclopropene **2** (eq 3).



To this end, we examined the reaction of 1-(trimethylsilyl)-cyclopropene-3,3-dicarboxylate **1a** with benzaldehyde in the presence of various nucleophilic catalysts (Table 1). We were pleased to find that in the presence of 25 mol % of DABCO **1a**, indeed, underwent the sila-MBH reaction to produce the expected cyclopropene **2a** in 42% yield (entry 1).[9] Next, it was found that electron-rich tris(2,4,6-trimethoxyphenyl)phosphine (TTMPP) was more efficient than other N- and P-based catalysts (entries 1−7). However, the yield of **2a** produced in the presence of 25 mol % of TTMPP in DMF at ambient temperature remained moderate (entry 7). Change of temperature did not improve the reaction yield (entries 8−9). To our delight, it was found that reducing the catalyst loading, together with the use of 1,4-dioxane as a solvent, allowed for a dramatic increase in the yield of the *sila*-MBH reaction, producing **2a** in 79% yield (entry 15).[10]

Naturally, with optimized conditions in hand, we examined the scope of this novel transformation with respect to the aldehyde component (Table 2). Gratifyingly, a wide selection of aryl and heteroaryl aldehydes (entries 1−7) reacted smoothly with **1a** to produce 1-(silyloxymethyl)cyclopropenes **2** in good yields. Ester-, methoxy-, and halo-substituents were well tolerated in this transformation. Notably, cinnamyl aldehyde, a compound possessing

Table 1. Optimization of the Reaction Conditions[a]

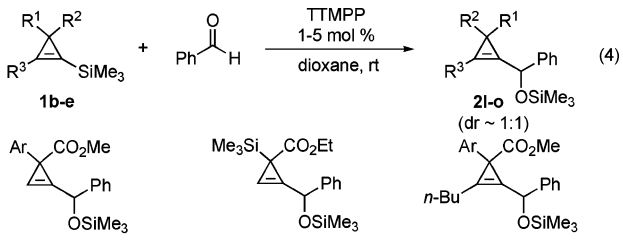


entry	catalyst[b]	mol %	solvent	temp	time, h	yield[c], %
1	DABCO	25	DMF	rt	3	42
2	DBU	25	DMF	rt	3	0
3	DMAP	25	DMF	rt	3	28
4	P(*t*-Bu)$_3$	25	DMF	rt	3	5
5	PPh$_3$	25	DMF	rt	3	12
6	PCy$_3$	25	DMF	rt	3	5
7	TTMPP	25	DMF	rt	3	57
8	TTMPP	25	DMF	0 °C	3	33
9	TTMPP	25	DMF	50 °C	3	42
10	TTMPP	5	DMF	rt	4.5	62
11	TTMPP	5	DMA	rt	4.5	62
12	TTMPP	5	DMSO	rt	4.5	64
13	TTMPP	5	1,4-dioxane	rt	4.5	68
14	TTMPP	5	THF	rt	4.5	66
15	**TTMPP**	**1**	**1,4-dioxane[d]**	**rt**	**6**	**79**

[a] 0.1 mmol scale; 1 M concentration; rt = room temperature. [b] DABCO = 1,4-diazabicyclo[2.2.2]octane; DBU = 1,8-diazabicyclo[5.4.0]undec-7-ene; DMAP = 4-(dimethylamino)pyridine; TTMPP = tris(2,4,6-trimethoxyphenyl)phosphine. [c] GC yield. [d] Reaction run using 2 M concentration, 0.5 mmol scale.

an activated double bond, reacted with **1a** highly chemo- and regioselectively[11] to produce 1,4-diene **2h** in good yield (entry 8). Remarkably, primary, secondary, and tertiary aliphatic aldehydes were equally efficient in sila-MBH reaction (entries 9−11), suggesting a low sensitivity of this reaction to steric hindrance at the α-position of aldehyde.

Next, we tested a series of unsymmetrically substituted 1-silyl-cyclopropenes **1b−e** in the reaction with benzaldehyde (eq 4). Both 3-aryl and 3-silyl substrates, as well as tetrasubstituted cyclopropene, produced the corresponding sila-MBH products **2l−o** in good to excellent yields, though as nearly equimolar mixtures of diastereomers. It was also found that the reaction was limited to cyclopropenes possessing electron-withdrawing groups at C-3. Presumably, this was required to decrease the energy of the cyclopropene's LUMO[12] for a more facile addition of nucleophilic catalyst.



Encouraged by the successful sila-MBH reaction of **1** with aldehydes, we then attempted the analogous reaction with activated ketones (eq 5). To our delight, we found that cyclopropene **1a**

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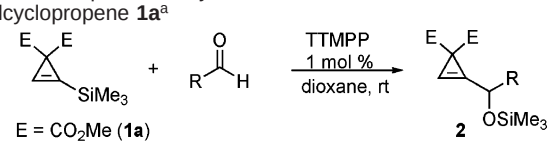
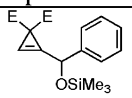
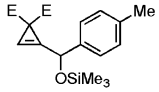
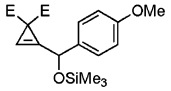
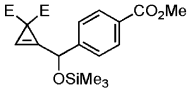
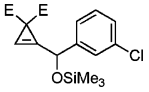
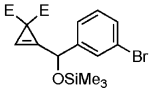
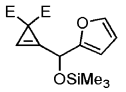
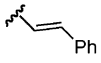
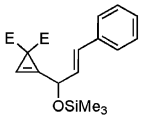
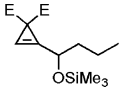
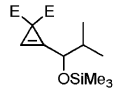
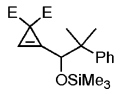
Table 2. Phosphine-Catalyzed Sila-MBH Reaction of 1-silylcyclopropene **1a**[a]

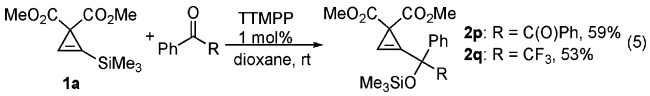


E = CO_2Me (**1a**) **2**

#	R	product		yield[b], %
1	Ph		**2a**	75
2	*p*-Tol		**2b**	75
3	*p*-$OMeC_6H_4$		**2c**	65
4	*p*-$CO_2MeC_6H_4$		**2d**	60
5	*m*-ClC_6H_4		**2e**	80
6	*m*-BrC_6H_4		**2f**	58
7	2-Furyl		**2g**	50
8			**2h**	76
9	*n*-Pr		**2i**	72
10	*i*-Pr		**2j**	76
11			**2k**	69

[a] Reaction conditions: **1a** (0.5 mmol), aldehyde (1.0 mmol), TTMPP (0.005 mmol), dioxane (0.25 mL). [b] Isolated yield.

reacted smoothly with 1,2-dicarbonyl compound to form α-silyloxyketone **2p**. Moreover, α,α,α-trifluoroacetophenone underwent reaction with **1a** to produce cyclopropene **2q** in reasonable yield (eq 5).[13] It deserves mentioning that, prior to the development of this protocol, there were no direct approaches toward 1-(silyloxymethyl)cyclopropene-3-carboxylates **2**. Indeed, these synthetically



useful building blocks[14] may not be obtained through the direct Rh(II)-catalyzed addition of diazocompounds to secondary propargyl alcohol derivatives, as this route is known to lead to the corresponding allenes.[15] An alternative dianion approach[16] requires hydrolysis of ester group and reesterification.

In summary, we developed a sila Morita−Baylis−Hillman reaction of readily available[17] 1-silylcylopropene-3-carboxylates with aldehydes and activated ketones, involving a 1,3-Brook rearrangement/elimination sequence. This novel protocol allows for the direct and efficient synthesis of 1-(silyloxymethyl)cyclopropenes, which are not easily available through existing methods. Further studies on expanding the scope[9] and elucidation of the precise mechanism of sila-MBH reaction are underway in our laboratories.

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

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(9) Simple vinylsilane, α-silyl acrylate, as well as non-silylated cyclopropenes, did not undergo this transformation. In contrast, a-silyl enones produced MBH product in moderate yield. Further studies of this transformation are underway in our laboratories.

(10) It was found that TTMPP causes notable decomposition of **1a**. Thus, lower catalyst loading allowed for higher material balance. See Supporting Information for details and full optimization data.

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