Ammonium Carboxylate-catalyzed [2,3]-Wittig Rearrangement of Silyl Enolates Generated from α-Allyloxy Esters

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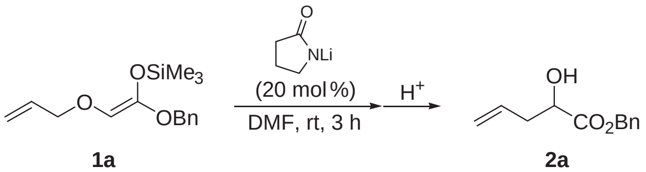
Silyl enolates that were generated from α-allyloxy esters afforded the corresponding [2,3]-Wittig rearrangement products in moderate to good yields on treatment with a catalytic amount of Lewis base such as tetrabutylammonium acetate or tetrabutylammonium 4-methoxybenzoate in DMF at room temperature.

Sigmatropic rearrangement of silyl enolates generated from α-allyloxy carbonyl compounds is the tool counted useful for the formation of new carbon–carbon bond. There are two possible thermal sigmatropic rearrangements of these enolates: namely, [3,3]-Claisen and [2,3]-Wittig rearrangements.[1] In the case of silyl enolates, thermal [3,3]-Claisen rearrangement is known to proceed selectively[2] while a report by Nakai et al. showed [2,3]-Wittig rearrangement of trimethylsilyl (TMS) enolates generated from α-allyloxy esters took place by using a catalytic amount of silyl triflate.[3]

In the course of our investigation on Lewis base-catalyzed reactions,[4–7] it was revealed that the nitrogen anions generated from amides or amines promoted the catalytic [2,3]-Wittig rearrangement of silyl enolates generated from α-allyloxy ketones effectively.[8] In order to make better use of synthetic utility of this reaction, it was considered to apply silyl enolates generated from α-allyloxy esters to the [2,3]-Wittig rearrangement despite their low reactivities for rearrangement compared with those of α-allyloxy ketones.[2e,9]

In the first place, Lewis base-catalyzed [2,3]-Wittig rearrangement of the TMS enolate generated from α-allyloxy benzyl ester **1a**[10] was tried in the presence of a catalytic amount of lithium 2-pyrrolidone in DMF at room temperature (Scheme 1). Then, the rearranged product **2a** was obtained only in 38% yield though lithium 2-pyrrolidone had been considered the most effective catalyst for the [2,3]-Wittig rearrangement of silyl enolates generated from α-allyloxy ketones.[8]

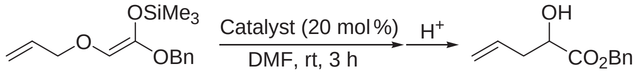


1a **2a** 38%

Scheme 1.

Then, Lewis base catalysts were screened in order to find an effective one for this reaction (Table 1). In the first place, the reaction was tried by using lithium acetate, but the desired product **2a** was obtained in 34% yield only (Entry 1). On the other hand, the reaction proceeded smoothly to afford **2a** in 70% yield when carried out with 20 mol % of tetrabutylammonium acetate ($AcONBu_4$, **3**, Entry 2). These results indicate that the nature of counter cation of acetate had an influence on this reaction and that the ammonium ion was an appropriate counter cation. Then, various tetrabutylammonium carboxylates were further screened so as to increase the yield of the rearranged product and tetrabutylammonium 4-methoxybenzoate ($4\text{-}MeOC_6H_4CO_2NBu_4$, **4**) was thus found also effective (Entry 4).[11]

Table 1. Screening of the Lewis base catalysts



1a **2a**

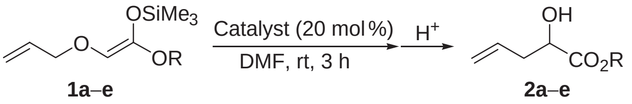
Entry	Catalyst	Yield[a]/%
1	AcOLi	34
2	$AcONBu_4$ (**3**)	70
3	$PhCO_2NBu_4$	49
4	$4\text{-}MeOC_6H_4CO_2NBu_4$ (**4**)	83
5	$2,4\text{-}(MeO)_2C_6H_3CO_2NBu_4$	71
6	$4\text{-}ClC_6H_4CO_2NBu_4$	30
7	$4\text{-}NO_2C_6H_4CO_2NBu_4$	trace

[a] Isolated yield.

Next, the ammonium carboxylate-catalyzed [2,3]-Wittig rearrangement was tried by using various TMS enolates generated from α-allyloxy esters in the presence of a catalytic amount of **3** or **4** in DMF at room temperature (Table 2). Trimethylsilyl enolates **1b** or **1c** having either an electron-donating or -withdrawing substituent in the phenyl group of the ester moiety afforded the [2,3]-Wittig rearrangement products in good yields (Entries 3–6) whereas enolate **1d** that possesses a strongly electron-withdrawing substituent such as trifluoromethyl afforded the desired product only in a moderate yield (Entries 7 and 8). On the other hand, no [2,3]-Wittig rearrangement product was detected when the reaction was carried out by using the TMS enolate **1e** generated from phenyl ester (Entries 9 and 10).

Further, effect of an allyloxy part contained in TMS enolates on this reaction was examined (Table 3). In the first place, ammonium carboxylate-catalyzed [2,3]-Wittig rearrangement was tried by using TMS enolate **1f** having an electron-donating methyl group at the allyloxy part (Entries 1 and 2). Then, the rearrangement product **2f** was obtained in low to moderate yields when either **3** or **4** was used for the catalyst. Next, TMS enolate **1g** which has an electronegative chlorine atom at the allyloxy part was examined and the corresponding [2,3]-Wittig rearrangement product **2g** was obtained in a good yield (Entries 3 and 4). These results indicate that the silyl enolates having an electron-withdrawing substituent of the allyloxy part promoted this rearrangement more effectively than the ones having an electron-donating substituent.

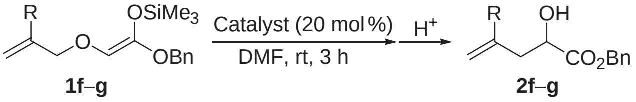
Table 2. Tetrabutylammonium carboxylate-catalyzed [2,3]-Wittig rearrangement of α-allyloxy ketene silyl acetals



Entry	R		Catalyst	Yield[a]/%
1	$PhCH_2$	**1a**	**3**	70
2	$PhCH_2$	**1a**	**4**	83
3	$4\text{-}MeOC_6H_4CH_2$	**1b**	**3**	82
4	$4\text{-}MeOC_6H_4CH_2$	**1b**	**4**	77
5	$4\text{-}ClC_6H_4CH_2$	**1c**	**3**	63
6	$4\text{-}ClC_6H_4CH_2$	**1c**	**4**	84
7	$4\text{-}CF_3C_6H_4CH_2$	**1d**	**3**	40
8	$4\text{-}CF_3C_6H_4CH_2$	**1d**	**4**	49
9	Ph	**1e**	**3**	n.d.[b]
10	Ph	**1e**	**4**	n.d.[b]

[a]Isolated yield. [b]n.d.; not detected.

Table 3. Effect of allyloxy part of silyl enolates for tetrabutylammonium carboxylate-catalyzed [2,3]-Wittig rearrangement



Entry	R		Catalyst	Yield[a]/%
1	Me	**1f**	**3**	23
2	Me	**1f**	**4**	40
3	Cl	**1g**	**3**	77
4	Cl	**1g**	**4**	80

[a]Isolated yield.

Thus, the [2,3]-Wittig rearrangement of silyl enolates generated from α-allyloxy esters proceeded smoothly in the presence of a Lewis base catalyst such as tetrabutylammonium 4-methoxybenzoate or tetrabutylammonium acetate in DMF to afford the desired products in moderate to good yields. Further development of this reaction is now in progress.

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10 The silyl enolates were synthesized from the corresponding α-allyloxy esters on successive treatments with lithium hexamethyldisilazide and chlorotrimethylsilane in THF at −78 °C. After the solvent was removed by evaporation, the residue was diluted with petroleum ether and filtered through Celite. After evaporation of the solvent, the resulted crude oily silyl enolate was used for the rearrangement without further purification. Content of the silyl enolate was determined by ^1H NMR analysis (270 MHz) using 1,3,5-trimethylbenzene as an internal standard.

11 Typical experimental procedure is as follows (Table 1, Entry 4): a) Preparation of a toluene solution of tetrabutylammonium 4-methoxybenzoate; To a solution of 4-methoxybenzoic acid (76.1 mg, 0.50 mmol) in methanol (3.0 mL) was added tetrabutylammonium hydroxide in methanol (37 wt %, 350.6 mg, 0.5 mmol). After the mixture was stirred 30 min, the solvent was removed under reduced pressure. The residue was azeotroped with toluene (3 mL × 3), and then dissolved in toluene (5 mL) to give a 0.1 M solution of tetrabutylammonium 4-methoxybenzoate. b) The procedure of tetrabutylammonium 4-methoxybenzoate-catalyzed [2,3]-Wittig rearrangement; A toluene solution of tetrabutylammonium 4-methoxybenzoate (0.35 mL, 0.035 mmol) was concentrated under reduced pressure and the residue was dissolved in DMF (0.5 mL). Then, the solution of silyl enolate **1a** (content: 79%, 61.0 mg, 0.173 mmol) in DMF (1.5 mL) was added at room temperature under argon atmosphere. The mixture was stirred for three hours at the same temperature, and aqueous HCl (1.0 M) was added. After stirring for 10 min, the mixture was extracted with Et_2O. Organic layer was washed with water and brine, and dried over anhydrous $MgSO_4$. After filtration and evaporation of the solvent, the crude product was purified by preparative TLC to afford **2a** (29.6 mg, 83%).

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