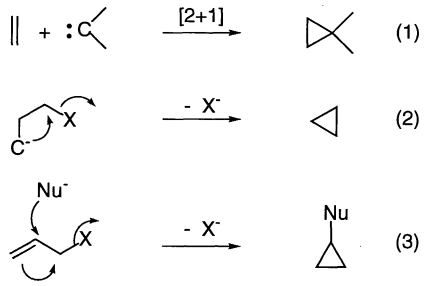
Cyclopropanation of Ketene Silyl Acetals with Allylic Acetates Using η^3-Allylpalladium-Pyridinylimidazole Catalysts

Akiharu Satake,*† Hiroyuki Koshino, and Tadashi Nakata
The Institute of Physical & Chemical Research (RIKEN), 2-1 Hirosawa, Wako, Saitama 351-0198

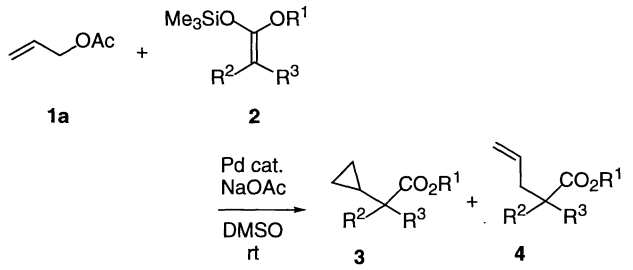
(Received October 6, 1998; CL-980769)

Highly selective cyclopropanation of ketene silyl acetals with allylic acetates was carried out in the presence of novel η^3-allylpalladium-pyridinylimidazole complexes and sodium acetate in DMSO at room temperature. When cinnamyl acetate was used as an allylic acetate, phenylcyclopropane derivative was obtained stereoselectively in 83% yield.

Cyclopropanes are useful compounds in organic synthesis because they can be easily transformed into various other organic molecules.[1] Because of its ring strain, cyclopropane ring is cleaved with heat, nucleophiles, and transition metals. Extensive work regarding cyclopropane formation has been reported, and it can generally be classified into [2 + 1] addition of carbens with olefins (eq.1 in Scheme 1), intramolecular nucleophilic substitution (eq.2 in Scheme 1), and their modifications. On the other hand, intramolecular cycloaddition accompanied with introduction of substituent groups (eq.3 in Scheme 1) is rare.[2] In our previous paper[3] we reported that this type of reaction shown in Scheme 2 proceeded using the η^3-allylpalladium pyridinylpyrazole catalysts **5** (Scheme 3). However, the reaction often accompanied considerable amount of allylated compound **4** with cyclopropane **3**.

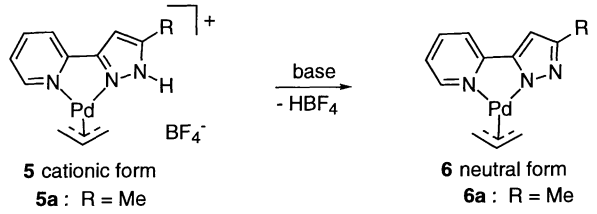


Scheme 1.

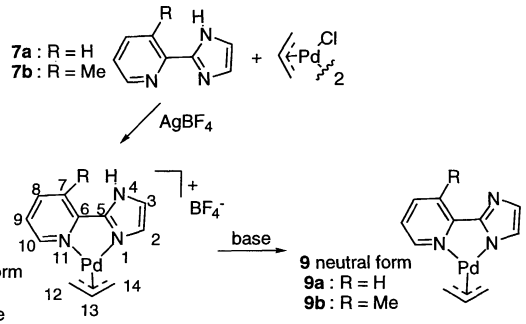


Scheme 2.

In the reaction the neutral complex **6** produced from the cationic complex **5** was an active species. The conversion of the cationic complex **5** into the neutral complex **6** occurred by the abstraction of the hydrogen atom on the nitrogen on the pyrazole ring. Similarly, other hetero aromatics, such as imidazole, triazole, indazole, and benzimidazole, are considered to have a property such as the pyrazole ligand. In particular, our interest has been attracted to imidazole ligands, as generally they have greater pK_as than those of pyrazoles.[4] The difference of pK_a may give the palladium metal great influence when the imidazole ligands form the η^3-allylpalladium complexes. In this paper we report highly selective cyclopropanation of ketene silyl acetals with allylic acetates using η^3-allylpalladium-pyridinylimidazole complexes **8**.



Scheme 3.

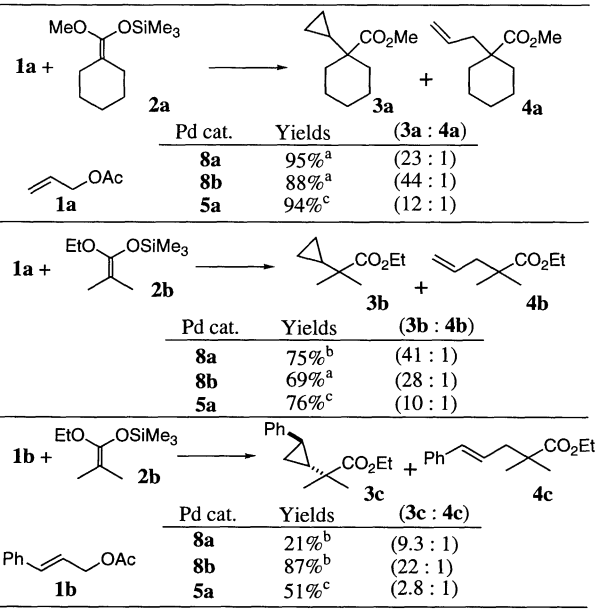


Scheme 4.

The cationic palladium-pyridinylimidazole complexes **8a** and **8b** were synthesized from pyridinylimidazole **7a**[5] and **7b**,[6] respectively, and π-allylpalladium chloride dimer by the similar procedure reported in the previous paper.[3] The cationic complex **8a**[7] was converted into a neutral form **9a**[8] by treatment of sodium methoxide in the mixture of CD_2Cl_2 and CD_3OD. Chemical shifts of N4 in ^{15}N NMR[9] drastically moved into 221.8 ppm from 139.9 ppm by conversion into **9a** from **8a**. Similarly, conversion of **8b** into **9b** was observed by NMR spectroscopic studies.

Reactions of ketene silyl acetals with allylic acetates were carried out in the presence of palladium-pyridinylimidazole complexes **8a** and **8b**, and sodium acetate in DMSO. Results are shown in Table 1. In the reaction conditions, cationic complexes **8a** and **8b** were converted into the neutral complexes **9a** and **9b**, respectively, *in situ*. It is clear that **8a** and **8b** are excellent catalysts for cyclopropanation by comparison with the results in the case of the pyridinylpyrazol complex **5a**. In the presence of **8a** or **8b**, selectivity of cyclopropanes **3a** and **3b** drastically heightened. Use of the catalyst **8b**, especially, heightened both

Table 1. Palladium-catalyzed reaction of allylic acetates with ketene silyl acetals



Pd cat.	Yields	(3a : 4a)
8a	95%[a]	(23 : 1)
8b	88%[a]	(44 : 1)
5a	94%[c]	(12 : 1)

Pd cat.	Yields	(3b : 4b)
8a	75%[b]	(41 : 1)
8b	69%[a]	(28 : 1)
5a	76%[c]	(10 : 1)

Pd cat.	Yields	(3c : 4c)
8a	21%[b]	(9.3 : 1)
8b	87%[b]	(22 : 1)
5a	51%[c]	(2.8 : 1)

Reaction conditions; allylic acetate **1** (1 mmol), ketene silyl acetal **2** (2 mmol), Pd catalyst (0.05 mmol), NaOAc (0.2 mmol), in DMSO (4 mL), rt. [a]Yield was determined by GLC and ^{1}H NMR (300 MHz) with internal standard (n-decane). [b]Isolated yield. [c]Ref. 3.

yield and selectivity of **3c** in the reaction of cinnamyl acetate **1b**. Unfortunately, reaction of allyl acetate with ketene silyl acetals of ethyl propionate and t-butyl acetate did not give cyclopropane. The reaction mechanism is considered to be similar to that in the case of pyridinylpyrazole complex. Thus, at the first stage

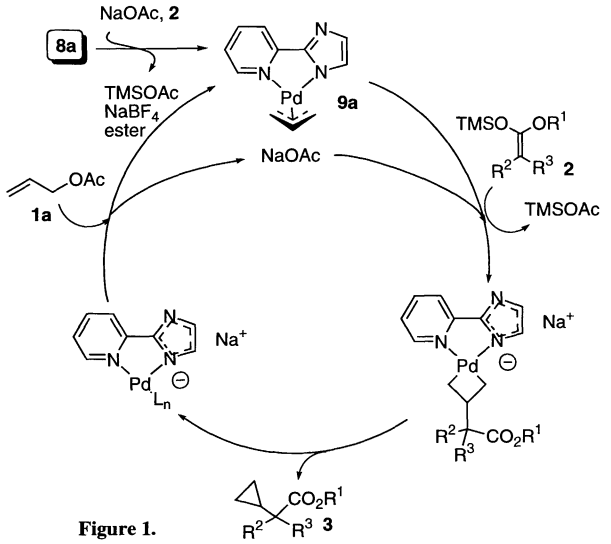


Figure 1.

cationic complex **8a** is converted into neutral complex **9a** under basic conditions,[11] and nucleophilic attack occurs on the central carbon of the η^3-allyl moiety to produce palladacyclobutane. The palladacyclobutane gives cyclopropane **3** and an active Pd (0) species, which react with allyl acetate to generate **9a** and sodium acetate again. Although the differences between pyrazole ligands and imidazole ligands are not clear at the present time, electronic effect seems to have large influence on the selectivity. We are investigating the effects of substituent groups including electron withdrawing and electron donating groups on the heteroaromatic ligands.

A.S. gratefully acknowledges the financial support by Special Postdoctoral Researchers Program in RIKEN. This work was supported in part by Special Project Funding for Basic Science (Essential Reaction) from RIKEN.

References and Notes

† Special Postdoctoral Researcher, Special Postdoctoral Researchers Program in RIKEN.

1 a) H. N. C. Wong, M.-Y. Hon, C.-W. Tse, Y.-C. Yip, J. Tanko, and T. Hudlicky, *Chem. Rev.*, **89**, 165 (1989). b) J. Salaün, *Chem. Rev.*, **89**, 1247 (1989).

2 a) L. S. Hegedus, W. H. Darlington, and C. E. Russell, *J. Org. Chem.*, **45**, 5193 (1980). b) H. M. R. Hoffmann, A. R. Otte, and A. Wilde, *Angew. Chem., Int. Ed Engl.*, **31**, 234 (1992). c) C. Carfagna, R. Galarini, A. Musco, and R. Santi, *J. Mol. Catal.*, **72**, 19 (1992). And references cited in Ref. 3.

3 A. Satake and T. Nakata, *J. Am. Chem. Soc.*, **120**, 10391 (1998).

4 For example; 1-methylimidazole: pK_a = 7.33, 1-methylpyrazole: pK_a = 2.06. G. Dedichen, *Ber.* **39**, 1831 (1906).

5 J. L. Hughey IV, S. Knapp, and H. Schugar, *Synthesis*, **1980**, 489.

6 **7b** was synthesized from 2-cyano-3-methylpyridine according to Ref. 5.

7 **8a**: ^{1}H NMR (CD_3OD : CD_2Cl_2 = 1 : 1, 600 MHz) δ 8.75 (br.d. 1H, J = 5.4 Hz), 8.19 (ddd, 1H, J = 7.8, 7.8, 1.5 Hz), 8.08 (br.d, 1H, J = 7.8 Hz), 7.60 (ddd, 1H, J = 7.8, 5.4, 1.5 Hz), 7.43 (d, 1H, J = 1.0 Hz), 7.31 (d, 1H, J = 1.0 Hz), 5.85 (tt, 1H, J = 12.7, 6.3 Hz), 4.41 (br, 1H), 4.35 (br, 1H), 3.48 (br, 1H), 3.30 (br, 1H). ^{13}C NMR (CD_3OD : CD_2Cl_2 = 1 : 1, 150 MHz) δ 154.98, 148.45, 147.91, 141.63, 131.45, 127.09, 121.86, 121.29, 118.46, 63.60, 58.31. ^{15}N NMR (CD_3OD : CD_2Cl_2 = 1 : 1) δ 221.3 (N11), 188.5 (N1), 139.9 (N4). mp 220°C~ (decomp.). Found: C, 34.52; H, 3.11; N, 10.79%. Anal Calcd. for $C_{11}H_{12}N_3PdBF_4$: C, 34.82; H, 3.19; N, 11.07%.

8 **9a**: ^{1}H NMR (CD_3OD : CD_2Cl_2 = 1 : 1, 600 MHz) δ 8.46 (br.d. 1H, J = 5.4 Hz), 7.93 (br.d, 1H, J = 8.3 Hz), 7.88 (ddd, 1H, J = 8.3, 8.3, 1.5 Hz), 7.18 (ddd, 1H, J = 8.3, 5.4, 1.0 Hz), 7.14 (br.s, 1H), 7.10 (br.s, 1H), 5.67 (tt, 1H, J = 12.7, 6.8 Hz), 4.13 (d, 1H, J = 6.8 Hz), 4.03 (d, 1H, J = 6.8 Hz), 3.26 (d, 1H, J = 12.7 Hz), 3.03 (d, 1H, J = 12.7 Hz). ^{13}C NMR (CD_3OD : CD_2Cl_2 = 1 : 1, 150 MHz) δ 154.76, 153.97, 153.51, 140.15, 130.99, 130.81, 122.92, 119.94, 116.47, 61.68, 54.38. ^{15}N NMR (CD_3OD : CD_2Cl_2 = 1 : 1) δ 221.8 (N4), 216.3 (N11), 183.2 (N1).

9 ^{15}N NMR spectra were obtained by ^{1}H - ^{15}N PEG-HMBC method at natural abundance[10], and chemical shifts are reported in ppm from NH_4NO_3 (0 ppm) in DMSO-d_6.

10 a) H. Koshino and J. Uzawa, *Kagaku To Seibutsu*, **33**, 252 (1995). b) R. C. Crouch and G. E. Martin, *J. Heterocycl. Chem.*, **32**, 1665 (1995). c) H. Shirahama, H. Koshino, J. Uzawa, K. Yamano, K. Konno, and K. Nakatsu, *Heterocycles*, **47**, 661 (1998). d) G. E. Martin, F. W. Crow, B. D. Kaluzny, J. G. Marr, G. D. Fate, and T. J. Gilbertson, *Magn. Reson. Chem.* **36**, 635 (1998). And references cited therein.

11 We reported that cationic palladium complexes which could not convert into neutral forms were almost unreactive in the cyclopropanation.[3]