BF_3-Catalyzed Reaction of Cyclobutene-1,2-dione Monoacetal and Its Vinylog with Allylsilanes. Regioselective Synthesis of 4-Allyl-4-ethoxycyclobutenones from Squaric Acid and Their Conversion to Bi- and Tricycloalkanones

Yoshihiko Yamamoto, Masatomi Ohno, and Shoji Eguchi*
Institute of Applied Organic Chemistry, Faculty of Engineering, Nagoya University, Chikusa, Nagoya 464-01

(Received March 15, 1995)

Regioselective allylation of 2,4- and 4,4-diethoxycyclobuteones was performed with allylsilanes in the presence of $BF_3•Et_2O$ *via* a common ethoxycarbenium ion intermediate. A merit of this reaction was demonstrated in an efficient conversion of the obtained 4-allyl-4-ethoxycyclobutenones to bi- and tricycloalkanones.

Squaric acid **1** has been utilized as a versatile C_4-building block, and various ring systems such as quinone, phenol, cyclopentenedione and butenolide were synthesized starting from **1**.[1] Recently, Moore reported that the thermolysis of 4-allylcyclobutenones gave bicyclo[3.2.0]heptenones *via* stereoselective thermal ring-opening and subsequent intramolecular [2+2] cycloaddition of resultant vinylketenes.[2] Thus, this method is of considerable value, if a feasible route to the 4-allylcyclobutenone having diverse substituents can be established. A wide variety of 4-substituted cyclobutenones are now accessible from **1** by means of the nucleophilic 1,2-addition of organolithium reagents.[3] 4-Allylcyclobutenones were obtained analogously; *i.e.* the addition of allylmagnesium bromide to dimethyl squarate produced a corresponding 1,2-adduct in good yield.[2] However, the extension of this method to obtain 4-allylcyclobutenones having a variety of substituents at 2-position was less effective. The addition of allyllithium was also reported to be unsuccessful.[2]

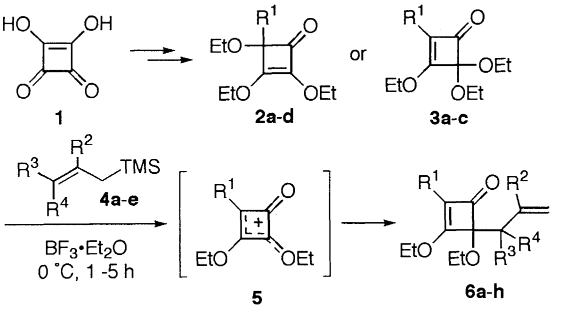
It was found by us that the $TiCl_4$-catalyzed addition of allyltrimethylsilane to 3-chlorocyclobutene-1,2-diones gave 1,2-adducts predominantly.[4] As for an electrophile, a carbonyl function is replaceable with an acetal which is, in some cases, more advantageous. This was true in the squaric acid system. Although our procedure was not applicable to the allylation of diethyl squarate, the problem was solved by choosing 2,4-diethoxy- and 4,4-diethoxycyclobutenone **2**[5] and **3**[6] as more reactive substrates for the Lewis acid-catalyzed allylation. Herein we wish to report a novel efficient approach for the substitution on a cyclobutene ring under electrophilic conditions.

Equation 1 depicts the new type of allylation *via* ethoxycarbenium ion species; catalytic action of a Lewis acid on monoacetal **3** or its vinylog **2** may produce an allylic cation **5** as a common intermediate, which followingly reacts with allylsilane **4**[7] selectively at more stabilized ethoxycarbenium ion site to afford a desired 4-allylated product **6**. Typically, a solution of methyl-substituted cyclobutenone **2a** and allylsilane **4a** (R^2, R^3, R^4=H) (3 equiv.) in dichloromethane was treated with $BF_3•Et_2O$ (1.2 equiv.) at 0 °C for 1h, and the expected 4-allyl-4-ethoxycyclobutenone **6a** was obtained in 84% yield after standard work-up and chromatographic separation. The similar reaction of phenyl and alkynyl-substituted **2b,c** afforded the corresponding products **6b,c** in 75 and 93% yields, respectively. Furthermore, an ester group on the ring did not interfere with this electrophilic allylation and thus the reaction of 4-(benzyloxycarbonylmethyl)-derivative **2d** was effected to give **6d** in 66% yield. Monoacetal **3** is another precursor for the generation of the common ethoxycarbenium ion intermediate **5**. In fact, monoacetals **3a-c** were subjected to allylation under the same conditions as employed for **2**, and the same products **6a-c** were obtained in comparable yields to those of the allylation of **2**.

Table 1. Synthesis and Thermolysis of 4-Allylcyclobutenone **6**

	R^1	R^2	R^3	R^4	**6**, % Yield[a]	**8**, % Yield
a	Me	H	H	H	79 (84)	98
b	Ph	H	H	H	72 (75)	73
c	C≡CPh	H	H	H	90 (93)	94
d	CH_2CO_2Bn	H	H	H	- (66)	83
e	Me	Me	H	H	72	94
f	Me	CH_2CO_2Me	H	H	82	99
g	Me	H	Ph	H	60	100
h	Me	H	Me	Me	50	57

a The yield obtained from **2** is indicated in parenthesis.

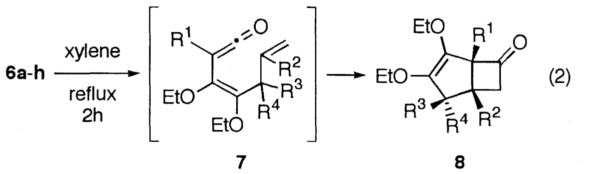


(1)

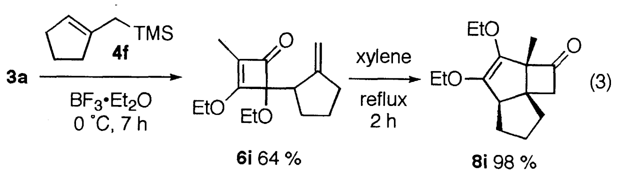
2, 3 a; R^1= Me **b**; R^1= Ph **c**; R^1= C≡CPh **d**; R^1= CH_2CO_2Bn
TMS= $Si(CH_3)_3$

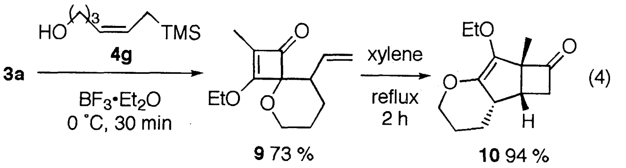
Modification of the substitution pattern in an allyl moiety must provide more elaborated 4-allyl-4-ethoxycyclobutenones, and hence, highly substituted bicyclo[3.2.0]heptenones. Thus, methallylsilane **4b** (R^2=Me, R^3, R^4=H) was reacted with monoacetal **3a** in the same manner as above for 5 h to give **6e** in 72% yield. Ester-functionalized allylsilane **4c** (R^2=CH_2CO_2Me, R^3=R^4=H) also afforded cyclobutenyl-enoate **6f** effectively. The similar reactions of cinnamylsilane **4d** (R^3=Ph, R^2=R^4=H) and prenylsilane **4e** (R^2=H, R^3=R^4=Me) furnished the corresponding products **6g,h** in 60 and 50% yields, respectively. Thus, these 4-allyl-4-ethoxycyclobutenones seem to be prepared quite conveniently and selectively by the use of organosilanes. The results are summarized in Table 1.

The obtained 4-allylcyclobutenones can be transformed to bicyclo[3.2.0]heptenones *via* an unsaturated ketene intermediate (*i.e.* **7**) as described above. An alcohol form (at 4-position) for this purpose was, in some cases, encountered by undesired side reactions.[2] In the present case, the hydroxyl group was already protected by an ethyl group, and therefore, cyclobutenones **6a-h** were directly and cleanly converted to bicycloheptenones **8a-h** in good yields by refluxing in xylene (Eq. 2, Table 1).



Further two examples demonstrate the versatility of the present method. Tricyclo[5.3.0.0^{1,4}]decenone derivative **8i**, which is interesting as a possible precursor of angular triquinane,[8] was successfully synthesized from **3a** and a cyclic allylsilane **4f** through cyclobutenone **6i** (eq. 3). When the spiro-annulation of an ω-hydroxy-substituted allylsilane with an acetal[9] was combined with our method, oxaspiro[3.5]nonenone **9** was prepared from acetal **3a** and an appropriate allylsilane **4g** in 73% yield, and **9** was converted cleanly to 11-oxatricyclo[5.4.0.0^{3,6}]undecenone derivative **10** in 94% yield (eq. 4).





In conclusion, a regioselective synthesis of 4-allyl-4-ethoxycyclobutenones with alkyl, aryl, and alkynyl substituents at 2-position was achieved by a novel Lewis acid-catalyzed reaction of allyltrimethylsilane with 2,4- and 4,4-diethoxycyclobutenones. These adducts were capable of transforming to the corresponding bicyclo[3.2.0]heptenones without appreciable side reactions, and this method was successfully applied to synthesis of functionalized tricyclic compounds.[10]

References and Notes

1 a) H. W. Moore and B. R. Yerxa, *Chemtracts: Org. Chem.*, **5**, 273 (1992); b) L. S. Liebeskind and J. Wang, *J. Org Chem.*, **58**, 3550 (1993); c) Y. Yamamoto, M. Ohno and S. Eguchi, *J. Org. Chem.*, **59**, 4707 (1994).

2 S. L. Xu, H. Xia and H. W. Moore, *J. Org. Chem.*, **56**, 6094 (1991).

3 a) M. W. Reed, D. J. Pollart, S. T. Perri, L. D. Foland and H. W. Moore, *J. Org. Chem.*, **53**, 2477 (1988); b) L. S. Liebeskind, R. W. Fengel, K. R. Wirtz and T. T. Shawe, *J. Org. Chem.*,**53**, 2482 (1988).

4 M. Ohno, Y. Yamamoto, Y. Shirasaki and S. Eguchi, *J. Chem. Soc., Perkin Trans. 1.*, **1993**, 263.

5 L. D. Foland, J. O. Karlsson, S. T. Perri, R. Schwabe, S. L. Xu, S. Patil and H. W. Moore, *J. Am. Chem. Soc.*, **111**, 975 (1989).

6 L. M. Gayo, M. P. Winters and H. W. Moore, *J. Org. Chem.*, **57**, 6896 (1992).

7 For the synthesis of allylsilanes used here, see: T. K. Sarkar, *Synthesis*, **1990**, 969, 1101.

8 N. H. Vo and B. B. Snider, *J. Org. Chem.*, **59**, 5419 (1994).

9 I. E. Markó, A. Mekhalfia, D. J. Bayston and H. Adams, *J. Org. Chem.*, **57**, 2211 (1992).

10 The structure of all the new compounds were confirmed on the basis of spectral inspections. The stereochemistry of **8g** and **10** were determined according to their coupling constants in the ^{1}H NMR spectra.