Available online at www.sciencedirect.com
ScienceDirect
Tetrahedron Letters 49 (2008) 3326–3329
Tetrahedron Letters

Stereoinduced cyclization of acyloxyalkenes using iodosylbenzene via a 1,3-dioxan-2-yl cation

Morifumi Fujita *, Hiroshi Suzawa, Takashi Sugimura, Tadashi Okuyama

Graduate School of Material Science, Himeji Institute of Technology, University of Hyogo, Kohto, Kamigori, Hyogo 678-1297, Japan

Received 8 February 2008; revised 4 March 2008; accepted 5 March 2008
Available online 8 March 2008

Abstract

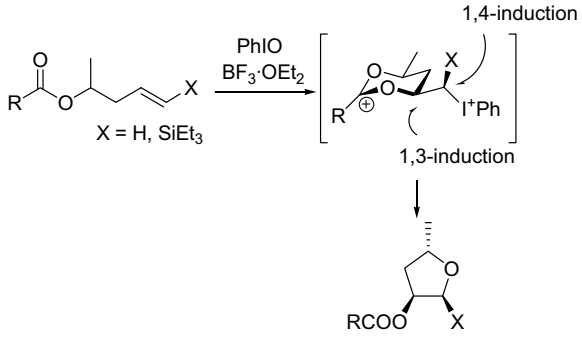
Reactions of pent-4-en-2-yl carboxylates and their derivatives with iodosylbenzene gave 2,4-disubstituted and 2,3,5-trisubstituted tetrahydrofurans with high diastereomeric ratio. The tetrahydrofuranylation may proceed via a 1,3-dioxan-2-yl cation intermediate generated by the participation of the internal acyloxy group in electrophilic attack of hypervalent iodine(III) toward acyloxyalkenes. Steric regulation owing to the cyclic structure of the cation accounts for the high stereoselectivity of the tetrahydrofuranylation.

Keywords: Tetrahydrofuran; Neighboring group participation; Iodosylbenzene; Hypervalent iodine

(Diacetoxyiodo)benzene and its derivatives are practically useful organohypervalent iodine(III) reagents for oxidation of various functionalities owing to their environmentally friendly nature and high selectivity.[1,2] They undergo oxidative O-[3] and N-cyclizations[4] of π-electron donors to yield heterocyclic products through radical and polar mechanisms. Stereoselective cyclization has been achieved through a radical mechanism by the reactions with organohypervalent iodine(V) reagents,[5] while there are few examples of diastereoselective O- and N-cyclizations using organoiodine(III) in a polar mechanism; Spirocyclization of arenes proceeded with high diastereoselectivity,[3e,4g] and intramolecular ene reaction of hydrazide giving δ-lactam resulted in a diastereomeric ratio of 3:1.[4a]

We have recently found that the reaction of but-3-enyl carboxylates with iodosylbenzene in the presence of $BF_3{\cdot}OEt_2$ gave 3-acyloxytetrahydrofurans.[6] The internal acyloxy group may participate in the electrophilic addition of iodine(III) to the C–C double bond in an *anti* fashion to give a 1,3-dioxan-2-yl cation intermediate. We envisaged that the stereoface-selectivity of the electrophilic addition of iodine(III) would be controlled by the stereogenic center at the remote 3-position owing to the intermediary formation of the six-membered ring as illustrated in Scheme 1. On this stage of tetrahydrofuranylation, 1,3- and 1,4-stereoinduction (Tables 1 and 2) would be achieved to provide 2,3,5-trisubstituted tetrahydrofurans in a diastereoselective manner.

Pent-4-en-2-yl carboxylates **1** were subjected to the reaction with iodosylbenzene in the presence of $BF_3{\cdot}OEt_2$ in dichloromethane (Table 1). The reaction gave 4-acyloxy-2-methyltetrahydrofuran **2** as a diastereomeric mixture.

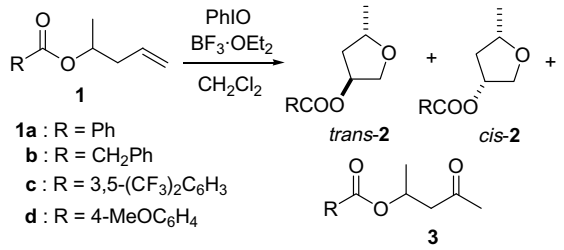


Scheme 1. Stereocontrol via a 1,3-dioxan-2-yl cation.

* Corresponding author. Tel.: +81 791 58 0170; fax: +81 791 58 0115.
E-mail address: fuji@sci.u-hyogo.ac.jp (M. Fujita).

0040-4039/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tetlet.2008.03.010

Table 1
Reaction of pent-4-en-2-yl carboxylates



Subst.	Temp. (°C)	*trans*-**2**/*cis*-**2**/**3**[a]	Yield[b] (%)	
			2 (trans/cis)[c]	**3**
1a	0	58:22:20	49 (73:27)	8
1a	−78	90:9:1	72 (90:10)	
1b	0	61:31:8	52 (64:36)	2
1b	−78	95:2:3	61 (97:3)	
1c	0	60:20:20	44 (75:25)	8
1c	−78	90:0:10	69 (>98:2)	
1d	0	65:17:18	48 (79:21)	3
1d	−78	85:10:5	71 (89:11)	

[a] Product distribution of the crude products.
[b] Isolated yield.
[c] Values in parentheses are the ratio of *trans*-**2**/*cis*-**2**.

The diastereoselectivity depends on the reaction temperature and also on the structure of the acyloxy group. The reaction of the benzoyloxy substrate **1a** gave a mixture of *trans*-**2a**/*cis*-**2a** with the ratio of 7:3 at the reaction temperature of 0 °C, and the diastereoselectivity improved at −78 °C to be 9:1. The phenylacetoxy (**1b**) and bis(trifluoromethyl)benzoyloxy (**1c**) substrates gave higher diastereomeric ratios at −78 °C.

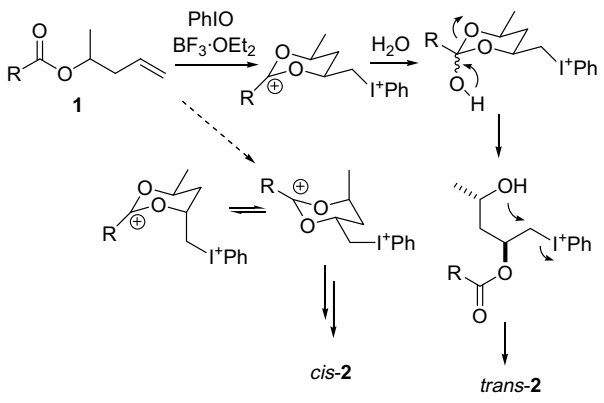
Preferential formation of the *trans*-tetrahydrofuran is compatible with stability of the 1,3-dioxan-2-yl cation intermediate (Scheme 2). The trans product is generated from the cis isomer of the 1,3-dioxan-2-yl cation, in which the substituents at the 4- and 6-positions mainly take an equatorial orientation. One of the two substituents at the 4- and 6-positions is forced to an axial orientation in the case of the *trans*-1,3-dioxan-2-yl cation that provides the minor *cis*-**2**.

The high selectivity[7] of the 1,3-stereoinduction suggests that the nucleophilic addition of the internal acyloxy group takes place synchronously with the electrophilic addition of iodine(III) to the double bond. The cyclic structure of the 1,3-dioxan-2-yl cation may make the 1,3-stereoinduction effective. If the electrophilic addition of iodine(III) proceeded independently of the nucleophilic participation of the internal acyloxy group, the iodine reagent should differentiate the diastereoface of the acyclic alkene.

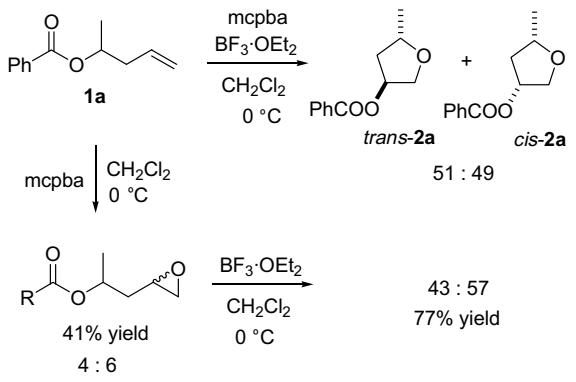
In order to demonstrate advantages of the 1,3-stereoinduction due to the cyclic cation intermediate, oxidation of **1a** with *m*-chloroperbenzoic acid (mcpba) was carried out in the presence of $BF_3{\cdot}OEt_2$ at 0 °C (Scheme 3). The reaction with mcpba also gave the tetrahydrofuran product **2a**, but the diastereomeric ratio was 1:1 of *trans*-**2a** and *cis*-**2a**. The reaction with mcpba proceeds via epoxides, and the diastereomeric outcome must be fated before the participation of the acyloxy group. The stepwise reaction of **1a** to **2a** via the epoxide also resulted in a low selectivity; Epoxidation of **1a** gave a 4:6 diastereomeric mixture of epoxides, which was treated with $BF_3{\cdot}OEt_2$ to give *trans*-**2a** and *cis*-**2a** in a ratio of 4:6. The rearrangement of the epoxide may stereospecifically proceed via a bicyclic ortho ester as reported previously.[8] Thus, the high stereoselectivity of the electrophilic attack of iodine(III) toward **1** may be attributed to the cyclic cation intermediate generated by the participation of the acyloxy group.[9]

The diastereoselectivities observed for the substrates with different acyloxy groups are also consistent with the participation mechanism of the internal acyloxy group in the stereo-determining step. Nucleophilicity of the acyloxy moiety of **1b** and **1c** is lower than that of **1a** and **1d**. The decrease in the nucleophilicity should increase the activation energy for the formation of the 1,3-dioxan-2-yl cation, and thus, enhance the difference in energy of the transition states leading to the *cis*- and *trans*-1,3-dioxan-2-yl cations.

In our previous reports,[6b] the tetrahydrofuranylations of (*E*)- and (*Z*)-4-(triethylsilyl)but-3-enyl carboxylates stereospecifically gave *cis*- and *trans*-3-acyloxy-2-(triethylsilyl)tetrahydrofurans, respectively. Thus, introduction of a silyl group at the terminal vinylic position of substrate **1** would provide the route to the corresponding



Scheme 2. Stereochemical outcome of tetrahydrofuranylation.



Scheme 3. Tetrahydrofuranylation via epoxides.

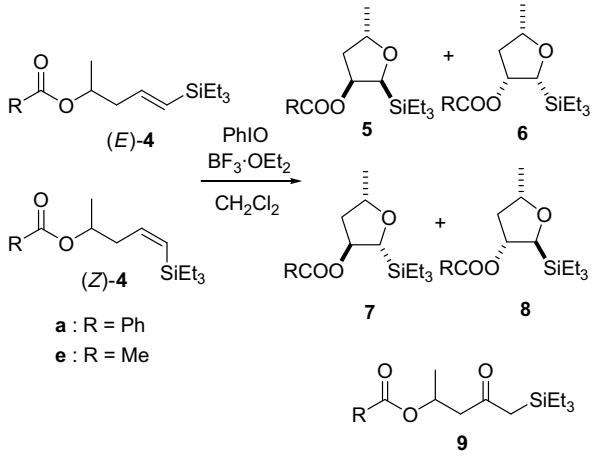
2,3,5-trisubstituted tetrahydrofurans. The reaction of (*E*)-5-(triethylsilyl)pent-4-en-2-yl carboxylates (**4**) with iodosylbenzene gave two isomers out of the four possible 3-acyloxy-5-methyl-2-silyltetrahydrofurans, **5**, **6**, **7**, and **8**, together with α-silyl ketone **9** (Table 2). The two tetrahydrofurans **5** and **6** obtained from (*E*)-**4** have the 2,3-cis-configuration. This stereochemistry is rationalized by *anti* participation of the acyloxy group in the electrophilic attack of iodine(III) and the ensuing S_N2 in the departure of the phenyliodonio group, and is in complete agreement with the stereospecific reaction of (*E*)-4-(triethylsilyl)but-3-enyl carboxylates. The major isomer **5** is derived from the preferred 4,6-di-equatorial dioxanyl cation, and minor **6** is from the axial form. The sense of stereochemical outcomes of the trisubstituted tetrahydrofurans is compatible with that of **2**.

The reaction of (*Z*)-**4e** preferentially gave diastereomer **7e** of 3,5-trans- and 2,3-trans-configurations. The 3,5-trans-configuration may be attributed to the preferential formation of the di-equatorial dioxanyl cation, and the 2,3-trans-configuration results from the (*Z*)-configuration of the substrate. Proton NMR (600 MHz) analyses of the crude products provided no sign of the fourth diastereomer **8e**, which is expected to be obtained as a minor isomer as discussed above. The reaction of (*Z*)-**4e** gave an unexpected isomer **5e**, which is the major isomer obtained from the *E* substrate. The formation of **5** from the *Z* substrate can be explained by a slight loss of the stereoselectivity in the last step forming the tetrahydrofuran ring of **7** owing to partial contribution of S_N1 to the departure of the phenyliodonio group.[10]

In the reaction of silyl-substituted substrate **4**, considerable amount of α-silyl ketone **9** was obtained as a side product, which may form via 1,2-elimination of the 1,3-dioxan-2-yl cation. The formation of **9** was reduced by replacing the benzoyloxy group in **4a** with an acetoxy group (**4e**) and by the reaction in the presence of water (TsOH). The acceleration of trapping of the dioxanyl cation with water may suppress the 1,2-elimination to promote the formation of tetrahydrofuran products. Under these optimized conditions, effective and stereoselective formation of the silyl-substituted tetrahydrofurans[11] was achieved.

In summary, 1,3- and 1,4-stereoinduction have been achieved in oxidative tetrahydrofuranylation of acyloxyalkenes with iodosylbenzene. The stereoselectivity is well controlled by the stereochemistry of the 1,3-dioxan-2-yl cation intermediate.

Table 2
Reaction of 5-silylpent-4-en-2-yl carboxylates



Subst.	Temp. (°C)	Yield (%)	
		5 + **6** + **7** + **8** (**5**/**6**/**7**/**8**)	**9**
4a (*E*/*Z* = 98:2)	−78	7 (86:14:—:—)	47
4a (*E*/*Z* = 98:2)[a]	−78	14 (86:14:—:—)	34
4a (*E*/*Z* = 98:2)[b]	−40	57 (88:12:—:—)	0
4e (*E*/*Z* = 98:2)	−78	45 (83:17:<2:—)	20
4e (*E*/*Z* = 98:2)[a]	−78	64 (88:12:<2:—)	16
4e (*E*/*Z* = 98:2)[b]	−40	62 (89:11:<2:—)	0
4e (*E*/*Z* = 1:99)[a]	−40	42 (5:<2:95:—)	15
4e (*E*/*Z* = 1:99)[b]	−40	69 (4:<2:96:—)	0

[a] In the presence of H_2O (1% v/v).

[b] (Hydroxy(tosyloxy)iodo)benzene was prepared by the treatment of (diacetoxyiodo)benzene with *p*-toluenesulfonic acid mono hydrate, and was employed in place of iodosylbenzene.

Acknowledgment

This work was partially supported by KAKENHI (19550050) from Japan Society for the Promotion of Science (JSPS).

Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.tetlet.2008.03.010.

References and notes

1. (a) Varvoglis, A. *The Organic Chemistry of Polycoordinated Iodine*; VCH: New York, 1992; (b) Varvoglis, A. *Hypervalent Iodine In Organic Synthesis*; Academic Press: San Diego, 1997; (c) *Hypervalent Iodine Chemistry*; Wirth, T., Ed.; Springer: Berlin, 2003.
2. For recent reviews, see: (a) Varvoglis, A. *Tetrahedron* **1997**, *53*, 1179–1255; (b) Wirth, T.; Hirt, U. H. *Synthesis* **1999**, 1271–1287; (c) Zhdankin, V. V.; Stang, P. J. *Chem. Rev.* **2002**, *102*, 2523–2584; (d) Moriarty, R. M. *J. Org. Chem.* **2005**, *70*, 2893–2903; (e) Wirth, T. *Angew. Chem., Int. Ed.* **2005**, *44*, 3656–3665; (f) Richardson, R. D.; Wirth, T. *Angew. Chem., Int. Ed.* **2006**, *45*, 4402–4404; (g) Silva, L. F., Jr. *Molecules* **2006**, *11*, 421–434; (h) Ochiai, M. *Chem. Record* **2007**, *7*, 12–23.
3. (a) Ochiai, M.; Fujita, E.; Arimoto, M.; Yamaguchi, H. *J. Chem. Soc., Chem. Commun.* **1982**, 1108–1109; (b) Ochiai, M.; Takaoka, Y.; Masaki, Y.; Inenaga, M.; Nagao, Y. *Tetrahedron Lett.* **1989**, *30*, 6701–6704; (c) Varma, R. S.; Saini, R. K.; Prakash, O. *Tetrahedron Lett.* **1997**, *38*, 2621–2622; (d) Madsen, J.; Viuf, C.; Bols, M. *Chem. Eur. J.* **2000**, *6*, 1140–1146; (e) Drutu, I.; Njardarson, J. T.; Wood, J. L. *Org. Lett.* **2002**, *4*, 493–496; (f) Boye, A. C.; Meyer, D.; Ingison, C. K.; French, A. N.; Wirth, T. *Org. Lett.* **2003**, *5*, 2157–2159; (g) Miyamoto, K.; Hirobe, M.; Saito, M.; Shiro, M.; Ochiai, M. *Org.*

Lett. **2007**, *9*, 1995–1998; (h) Browne, D. M.; Niyomura, O.; Wirth, T. *Org. Lett.* **2007**, *9*, 3169–3171.

4. (a) Scartozzi, M.; Grondin, R.; Leblanc, Y. *Tetrahedron Lett.* **1992**, *33*, 5717–5720; (b) Serna, S.; Tellitu, I.; Domínguez, E.; Moreno, I.; SanMartin, R. *Org. Lett.* **2005**, *7*, 3073–3076; (c) Du, Y.; Liu, R.; Linn, G.; Zhao, K. *Org. Lett.* **2006**, *8*, 5919–5922; (d) Tellitu, I.; Serna, S.; Herrero, M. T.; Moreno, I.; Domínguez, E.; SanMartin, R. *J. Org. Chem.* **2007**, *72*, 1526–1529; (e) Lu, H.; Chen, Q.; Li, C. *J. Org. Chem.* **2007**, *72*, 2564–2569; (f) Fan, R.; Pu, D.; Wen, F.; Wu, J. *J. Org. Chem.* **2007**, *72*, 8994–8997; (g) Dohi, T.; Maruyama, A.; Minamitsuji, Y.; Takenaga, N.; Kita, Y. *Chem. Commun.* **2007**, 1224–1226.
5. (a) Nicolaou, K. C.; Zhong, Y.-L.; Baran, P. S. *Angew. Chem., Int. Ed.* **2000**, *39*, 622–625; (b) Nicolaou, K. C.; Baran, P. S.; Zhong, Y.-L.; Sugita, K. *J. Am. Chem. Soc.* **2002**, *124*, 2212–2220; (c) Nicolaou, K. C.; Baran, P. S.; Zhong, Y.-L.; Barluenga, S.; Hunt, K. W.; Kranich, R.; Vega, J. A. *J. Am. Chem. Soc.* **2002**, *124*, 2233–2244.
6. (a) Fujita, M.; Okuno, S.; Lee, H. J.; Sugimura, T.; Okuyama, T. *Tetrahedron Lett.* **2007**, *48*, 8691–8694; (b) Fujita, M.; Lee, H. J.; Sugimura, T.; Okuyama, T. *Chem. Commun.* **2007**, 1139–1141; For a related paper, see: (c) Fujita, M.; Lee, H. J.; Okuyama, T. *Org. Lett.* **2006**, *8*, 1399–1401.
7. (a) Oxidative cyclization of pent-4-en-2-ol leading to 4-hydroxy-2-methyltetrahydrofuran has been achieved by titanium silicate-1 catalysis. The *trans*/*cis* ratio of the tetrahydrofuran product was 72:28; (b) Bhaumik, A.; Tatsumi, T. *Chem. Commun.* **1998**, 463–464.
8. (a) Coxon, J. M.; Hartshorn, M. P.; Swallow, W. H. *J. Org. Chem.* **1974**, *39*, 1142–1148; (b) Coxon, J. M.; Hartshorn, M. P.; Swallow, W. H. *J. Chem. Soc., Chem. Commun.* **1973**, 261–262; (c) Coxon, J. M.; Hartshorn, M. P.; Swallow, W. H. *Aust. J. Chem.* **1973**, *26*, 2521–2526; (d) Chmielewski, M.; Guzik, P.; Hintze, B.; Daniewski, W. M. *Tetrahedron* **1985**, *41*, 5929–5932; (e) Dhokte, U. P.; Rao, A. S. *Org. Prep. Proced. Int.* **1992**, *24*, 13–20; (f) Wipf, P.; Xu, W. *J. Org. Chem.* **1993**, *58*, 5880–5882; (g) Wipf, P.; Aslan, D. C. *J. Org. Chem.* **2001**, *66*, 337–343.
9. (a) Poor diastereoselectivity in the tetrahydrofuranylation via epoxide suggests that the reaction with iodosylbenzene does not proceed via epoxide. The reaction of silyl-substituted substrate with mcpba in the presence of $BF_3{\cdot}OEt_2$ gave no tetrahydrofuran product, probably because of the tendency for silylepoxide to give silyl enol ether as a rearranged product.[9b] This indicates that the tetrahydrofuranylation using iodosylbenzene takes place through a different pathway from that of the rearrangement of epoxide. Direct oxygen atom transfer from iodosylarene derivatives to alkenes has been observed in a special case; epoxidation of enones with oxide-λ^3-iodane[9c]; (b) Fleming, I.; Newton, T. W. *J. Chem. Soc., Perkin Trans. 1* **1984**, 119–123; (c) Ochiai, M.; Nakanishi, A.; Suefuji, T. *Org. Lett.* **2000**, *2*, 2923–2926.
10. (a) Excellent nucleofugality of phenyliodono group[10b] may make the generation of an α-silyl carbocation possible; (b) Okuyama, T.; Takino, T.; Sueda, T.; Ochiai, M. *J. Am. Chem. Soc.* **1995**, *117*, 3360–3367.
11. (a) Diastereoselective preparation of 3-silyltetrahydrofurans has been achieved by 3+2 cycloaddition of allylic silanes and aldehydes.[11b,c] Our approach to 2-silyltetrahydrofurans is complementary to the 3+2 cycloaddition for selective preparations of silyl-substituted tetrahydrofurans; (b) Panek, J. S.; Beresis, R. *J. Org. Chem.* **1993**, *58*, 809–811; (c) Chabaud, L.; James, P.; Landais, Y. *Eur. J. Org. Chem.* **2004**, 3173–3199.