Organic Process Research & Development **2010,** *14,* 728–731

Effect of Phase-Transfer Catalyst on Stereochemistry of *tert*-Butyl-3-aryl(alkyl)-Substituted Glycidates

Anna Kowalkowska and Andrzej Jończyk*

Warsaw University of Technology, Faculty of Chemistry, Noakowskiego St. 3, 00-662 Warszawa, Poland

Abstract:

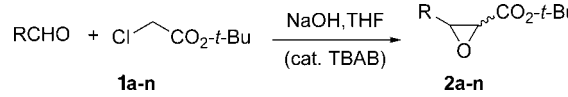
Darzen's condensation of *tert*-butyl-chloroacetate with aromatic, α,β-unsaturated, and aliphatic aldehydes in the presence of sodium hydroxide, afforded *tert*-butyl-glycidates, with *trans*/*cis* ratios 2.38−7.75. When TBAB was added as catalyst, the ratio reversed to *cis*/*trans* 1.67−4.52. Rate constants of halohydrin anion formations, their cyclization, and hydrolysis of diastereoisomers of glycidates as well as the structure of the corresponding conformers of halohydrin anions are considered to explain these results.

Introduction

Oxirane rings present in substituted glycidic esters are easily cleaved by electrophilic or nucleophilic reagents; hence, such esters are useful substrates for synthesis and industrial processes. Pure diastereoisomers or enantiomers of glycidates are useful intermediates, e.g. for the preparation of (2*R*,3*S*)-3-phenylisoserine, which constitutes the side chain of the oncology drugs taxol and taxotere,[1] or for the preparation of (2*S*,3*S*)-diltiazem[2] (for heart disease).

The glycidic esters are synthesized by the reaction of alkyl chloroacetates with aldehydes or ketones promoted by a base in a suitable solvent (Darzen's condensation[3]). Of the many bases and solvents used for that purpose, alkali metal hydroxides (solid or concentrated aqueous solutions), along with a quaternary ammonium salt (quat, Q^+X^-)[4] or a crown ether as a catalyst and an aprotic, nonpolar solvent have found wide application. The reactions of isopropyl- or *tert*-butyl-chloroacetate with aldehydes and ketones carried out in the presence of solid sodium hydroxide in THF, without a phase-transfer catalyst, afford glycidates in good yields,[5] but the addition of a catalyst to such a two-phase system often increases the rate and yield of the Darzen's condensation.[6−8]

Scheme 1. **Darzen's Reaction**



1a-n **2a-n**

Results and Discussion

We report here that the stereochemical outcome of the Darzen's glycidate synthesis, carried out in the presence of solid sodium hydroxide in THF, depends on the presence of a catalyst, tetrabutylammonium bromide (TBAB). Thus, phase-transfer catalytic (PTC) condensation (with 5 mol % of TBAB) of *tert*-butyl-chloroacetate with aromatic **1a**−**i**, α,β-unsaturated **1j**,**k** and aliphatic aldehydes **1l**−**n** gave *tert*-butyl-glycidates **1a**−**n** with *cis*/*trans* ratios from 1.67 to 4.52, while the same process carried out without a catalyst resulted in a reversal of the ratios to give glycidates **1a**−**d**,**g**−**j**,**l**−**n** with *trans*/*cis* ratios of 2.38−7.75 or afforded nearly pure *trans*-diastereoisomers in cases **1e**,**f**,**k** (Table 1).

Investigation of organic and acidified aqueous phases from uncatalyzed and catalyzed reactions of *tert*-butyl-chloroacetate with **1a** revealed that mass balance in the former case is ∼95%, while in the latter, ∼100%. However, aqueous phases contained some unidentified products, apart from 3-phenyl glycidic acid (^{1}H NMR data). On the other hand, the amount of impurities in organic phases from reactions in Table 1, except those with aldehydes **1g** and **1l**, did not exceed 2−5%.

We interrupted the processes from Table 1 when the mixtures evidently thickened; this effect occurred later in the case of catalyzed reactions. Hence, our data do not mean that rate of catalyzed reactions is lower than uncatalyzed. Condensation of *tert*-butyl-chloroacetate with aldehyde **1d** carried out for 10 min with TBAB or without TBAB revealed <1% of **1d** or still 5.5% of **1d**, respectively. The reactions of *tert*-butyl-chloroacetate with **1a** in the presence of 5% or stoichiometric amount of TBAB exhibited similar *cis*/*trans* ratio of **2a**, ∼3 after 15 min, but after a longer time *trans*-**2a** hydrolyzed at a slightly higher rate with a larger load of catalyst.

To compare our resultd with the literature,[6−8] we collected results of condensation of alkyl chloroacetates with benzaldehyde (**1a**) in a solid potassium hydroxide/THF system either with a catalyst (a quat) or without it (Table 2). These experiments demonstrate that more *cis*- than *trans*-glycidate (3.4−10.0) or even exclusively *cis*-isomer was isolated.

* Author for correspondence. E-mail: anjon@ch.pw.edu.pl.

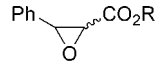
(1) Bunnage, M. E.; Davies, S. G.; Goodwin, C. J. *J. Chem. Soc., Perkin Trans. 1* **1994**, 2385–2391.
(2) Hashiyama, T. *Med. Res. Rev.* **2000**, *20*, 485–501.
(3) For a review of the Darzen's condensation see: Rosen, T. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon: Oxford, 1991; Vol. 2, pp 409−439.
(4) (a) Dehmlow, E. V.; Dehmlow, S. S. *Phase Transfer Catalysis*, 3rd ed.; Verlag Chemie, Weinheim, 1993. (b) Starks, C. M.; Liotta, M.; Halpern, M., *Phase-Transfer Catalysis*, Chapman & Hall; New York, London, 1994. (c) Mąkosza, M.; Fedoryński, M. *Catal Rev.* **2003**, *45*, 321–367. (d) Jończyk, A.; Kowalkowska, A. In *Science of Synthesis (Houben-Weyl)*; Majewski, M., Snieckus, V., Eds.; Thieme: Stuttgart, 2006; Vol. 8b, pp 1025−1028.
(5) Gadaj, A.; Kowalkowska, A.; Jończyk, A. *Pol. J. Chem.* **2008**, *82*, 577–584.
(6) Arai, S.; Suzuki, Y.; Tokumaru, K.; Shioiri, T. *Tetrahedron Lett.* **2002**, *43*, 833–836.
(7) Wang, Z.; Xu, L.; Mu, Z.; Xia, Ch.; Wang, H. *J. Mol. Cat. A: Chem.* **2004**, *218*, 157–160.
(8) Wang, Z.-T.; Xu, L.-W.; Xia, Ch.-G.; Wang, H.-Q. *Helv. Chim. Acta* **2004**, *87*, 1958–1962.

10.1021/op1000379
Published on Web 04/22/2010

Table 1. **Glycidates 2a−n prepared with and without TBAB**

			reactions with PT-catalyst (5% mol of TBAB)			reactions without PT-catalyst		
entry	**1**	R	time (min)	**2**, yield (%)[a]	ratio of *cis*/*trans* **2**	time (min.)	**2**, yield (%)[a]	ratio of *trans*/*cis* **2**
1	**a**	Ph	90	72	3.22:1[b]	60	54	6.55:1[b]
2	**b**	2-ClC_6H_4	60	60	2.00:1[b]	15	39	5.49:1[b]
3	**c**	3-ClC_6H_4	35	76	2.78:1[c]	12	67	3.66:1[c]
4	**d**	4-ClC_6H_4	120	70	3.94:1[b]	20	61	3.93:1[b]
5	**e**	4-MeC_6H_4	270	72	3.57:1[b]	60	67	16.56:1[b]
6	**f**	4-$MeOC_6H_4$	330	78	3.27:1[c]	70	47	ca. 90:1[c]
7	**g**	4-NCC_6H_4	140	41	2.23:1[c]	15	39	2.38:1[c]
8	**h**	3-C_4H_3S	210	84	2.84:1[c]	30	63	6.82:1[c]
9	**i**	1-$C_{10}H_7$	180	76	3.38:1[c]	150	42	4.85:1[c]
10	**j**	PhCH═CH	120	65	1.67:1[c]	75	67	7.75:1[c]
11	**k**	PhCH═C(Me)	195	80	2.36:1[c]	150	62	ca. 20:1[c]
12	**l**	Me_2CH	90	52	1.85:1[c]	60	48	3.67:1[c]
13	**m**	Et_2CH	300	78	3.05:1[c]	100	66	3.27:1[c]
14	**n**	*c*-C_6H_{11}	390	54	4.52:1[b]	150	51	4.54:1[b]

[a] Crude reaction mixtures contain less than 3% of aldehyde **1**. [b] Determined by GC. [c] Determined by ^{1}H NMR.



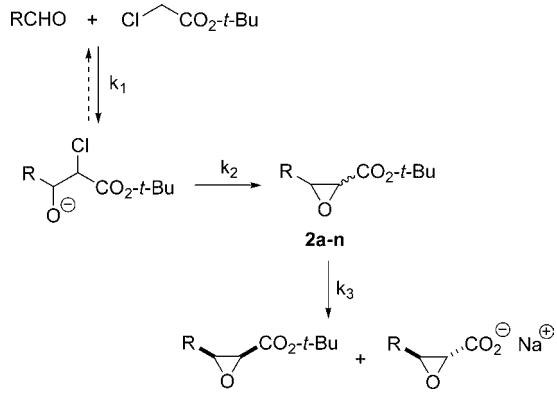
2a, R = *t*-Bu, **3**, R = Et

Table 2. **Comparison of the effect on the stereochemical outcome of Darzen's condensation of alkyl chloroacetates with benzaldehyde (1a) carried out with various PTCs**

entry	R	cat.	time (h)	yield (%)	*cis*/*trans*	lit.
1	Et	THAB[a]	24	78	3.4:1	8
2	Et	PsTEAC[b]	23	80	6.5:1	7
3	Et	PsTEAC[b]	70	17	9.0:1	7
4	Et	−	24	43	10:1	7
5	*t*-Bu	THAB[a]	22	52	*cis* only	6

[a] Tetrahexylammonium bromide. [b] Polystyrene-supported triethylammonium chloride.

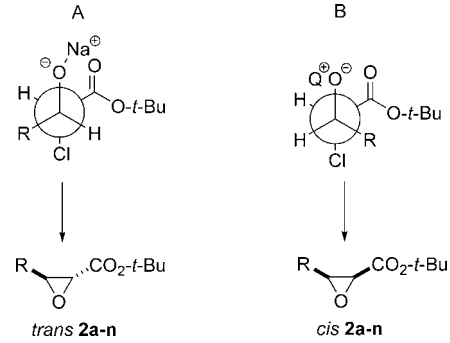
Scheme 2. **Darzen's condensation and hydrolysis of *trans*-glycidates**



To interpret our results, the following processes should be taken into account: the two-step reaction of chloroester with aldehydes and hydrolysis of *trans*-diastereoisomers of glycidates (Scheme 2).

According to density functional theory (DFT) modeling of Darzen's synthesis of glycidates, the first step—the formation of chlorohydrin anion—is rate limiting.[9] However, cyclization of either isomer of ethyl 2-chloro-3-hydroxy-3-phenylpropionate

Scheme 3. **Formation of *trans*- or *cis*-glycidates from halohydrin anions A and B**



trans **2a-n** *cis* **2a-n**

with sodium ethylate (but not with potassium carbonate, a weaker base) produced exclusively *trans*-glycidate **3**, indicating rapid isomerization of *syn*- into the *anti*-isomer of chlorohydrin before cyclization.[10] These results suggest that reaction conditions may decide which step of the Darzen's condensation is rate limiting.

Concerning the hydrolysis of *tert*-butyl-glycidates, we found that under PTC conditions *trans*-diastereoisomers hydrolyzed at much higher rate than *cis* ones. This observation allowed us to elaborate a simple synthesis of pure *tert*-butyl *cis*-3-substituted glycidates.[11] Therefore—depending on the base/solvent system used—the rate of halohydrin anion formation k_1 can be higher or lower than the rate of cyclization, k_2, but both rate constants are probably higher than the rate of hydrolysis of *trans*-*tert*-butyl-glycidates, k_3 (Scheme 2). The relationship of these rate constants are probably more complicated when easily hydrolyzed ethyl glycidates are synthesized by the Darzen's condensation. It had been suggested that the decrease of diastereoselectivity during the PT-catalyzed synthesis of ethyl 3-phenylglycidate (**3**) is due to the epimerization of the *cis*- into the *trans*-isomer,[7] but in our opinion the unequal hydrolysis of the newly formed esters is responsible for this result.

Returning to the data in Table 1, *trans*-isomers **2a**−**n** result from conformation A (Scheme 3) of the halohydrin anion, where the two largest substituents, R and *tert*-butoxycarbonyl, are

(9) Jezierska-Zięba, M.; Rode, J. E.; Fedoryński, M.; Cybulski, J.; Bajdor, K.; Dobrowolski, J. Cz. *J. Mol. Struct. (THEOCHEM)* **2008**, *849*, 1–7.

(10) Cabon, O.; Buisson, D.; Larcheveque, M.; Azerad, R. *Tetrahedron: Asymmetry* **1995**, *6*, 2211–2218.

(11) Jończyk, A.; Zomerfeld, T. *Tetrahedron Lett.* **2003**, *44*, 2359–2361.

located antiperiplanar. Conformation A is additionally stabilized by chelation with the sodium countercation.

Formation of the *cis*-isomers **2a**−**n**, in excess in the catalyzed processes, was unexpected since it requires participation of conformer B. In this case, chelation by a Q^+ (which stabilizes conformer A by Na^+) may be excluded. Evidently, different stereochemical outcome of catalyzed and uncatalyzed Darzen's condensation is due to Q^+ versus Na^+ present in ion pairs, but this statement requires explanation supported by experiments. It seems that sterically extended Q^+ found more space on the less crowded side of the chlorohydrine anion, forcing formation of conformer B which leads to *cis*-**2a**−**n**. Our results are in line with literature data[6−8] where *cis*-diastereoisomers of glycidates were formed in excess or exclusively (Table 2). However, the reported procedures lasted at least 22 h, sufficient to hydrolyze at least a portion of the *trans*-isomers. In our opinion, such hydrolysis which significantly affects the ratio of diastereoisomers of glycidates is insufficiently reported.

The fact that the catalyzed reactions occur in the organic phase of two-phase systems, while uncatalyzed reactions occur at the interfacial region, was used to explain the stereochemical outcome of α-chlorophenylacetonitrile condensation with benzaldehyde. A PT-catalyzed process afforded mainly the *trans*-2,3-diphenylglycidonitrile, while the uncatalyzed reaction led to both diastereoisomers in comparable amounts.[12] Neither this explanation nor the results of a diastereoselective Darzen's condensation of *N*,*N*-diphenyl-α-haloacetamides with aromatic aldehydes[13] satisfactorily explain our results, however. While we would have preferred a better mechanistic understanding of these results, the chemistry is useful for certain substitution patterns and suggests high diastereomeric ratios in the Darzen's reaction are possible by varying the substitutents.

Summary

Mixtures of both diastereoisomers of *tert*-butyl-3-aryl(alkyl)-substituted glycidates **2a**−**n** are usually prepared in good yield (Table 1). Synthetically useful are uncatalyzed reactions which afforded practically pure *trans*-products **1e**,**f**,**k**.

Experimental Section

^{1}H NMR (400 MHz) spectra were measured on a Varian Mercury 400BB spectrometer in $CDCl_3$. Gas chromatography analysis (GC) was performed on an Agilent 6850 series GC System fitted with a HP-50+ (30 m) column. TLC analysis was carried out using silica gel 60 F_{254} plates. During GC analysis the samples were injected at injector temperature 50−150 °C, depending on the bp of aldehyde. The reactions were interrupted when less than 96% of the aldehyde reacted (GC analysis) or traces of aldehydes remained in the mixtures (TLC analysis in the case of **2f**−**k**) (see Table 1).

General Procedure. Powdered NaOH (1.2 g, 30 mmol), THF (20 mL) and, in the case of catalyzed reactions, TBAB (0.16 g, 0.5 mmol) were stirred while mixture of aldehyde **1a**−**n** (10 mmol) and *tert*-butyl-chloroacetate (1.81 g, 1.72 mL, 12 mmol) was added at 10−15 °C. In the case of solid aldehydes **1d**,**g**, THF (5 mL) was placed in the flask, and the aldehydes **1d**,**g** were dissolved in THF (15 mL). The mixture was stirred at temperature 10−15 °C for the time given in Table 1, poured into ice (50 g), the phases were separated, the water phase was extracted with CH_2Cl_2 (3 × 30 mL), and the combined organic extracts were washed with water (3 × 30 mL) and dried over $MgSO_4$. The solvent was evaporated, and the residues were analyzed by GC and/or ^{1}H NMR. Mixtures of diastereoisomers were isolated by column chromatography and distilled via a Kugelrohr apparatus. Pure *cis*- and *trans*-diastereoisomers were isolated by column chromatography (eluent: hexane/ethyl acetate, gradient), the fractions were analyzed by GC, combined, evaporated, and distilled on Kugelrohr apparatus.

***tert*-Butyl-3-phenyl-oxirane-2-carboxylate (2a):**[5,6,11,14] colorless oil (when mixture was rich in *cis*-diastereoisomer) or colorless semi-crystalline mass (when mixture was rich in *trans*-diastereoisomer). Bp 100−103 °C/0.08 Torr or 112−115 °C/0.12 Torr (Kugelrohr).

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.17 (s, *t*-Bu, 9H *cis*), 1.51 (s, *t*-Bu, 9H *trans*), 3.40 (d, J = 1.6 Hz, 1H *trans*, $CHCO_2t$-Bu), 3.70 (d, J = 4.8 Hz, 1H *cis*, $CHCO_2t$-Bu), 4.01 (d, J = 1.6 Hz, 1H *trans*, ArC*H*), 4.21 (d, J = 4.8 Hz, 1H *cis*, ArC*H*), 7.25−7.44 (m, 5H *cis* + *trans*, ArH).

***tert*-Butyl-3-(2-chlorophenyl)-oxirane-2-carboxylate (2b):**[6,15] yellowish oil. Bp 114−117 °C/0.08 Torr or 108−111 °C/0.05 Torr (Kugelrohr).

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.16 (s, *t*-Bu, 9H *cis*), 1.52 (s, *t*-Bu, 9H *trans*), 3.26 (d, J = 1.6 Hz, 1H *trans*, $CHCO_2t$-Bu), 3.80 (d, J = 4.8 Hz, 1H *cis*, $CHCO_2t$-Bu), 4.31 (d, J = 4.8 Hz, 1H *cis*, ArC*H*), 4.34 (d, J = 1.6 Hz, 1H *trans*, ArC*H*), 7.21−7.52 (m, 4H *cis* + *trans*, ArH).

***tert*-Butyl-3-(3-chlorophenyl)-oxirane-2-carboxylate (2c):** colorless oil. Bp 116−119 °C/0.10 Torr or 107−111 °C/0.08 Torr (Kugelrohr).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.22 (s, *t*-Bu, 9H *cis*), 1.51 (s, *t*-Bu, 9H *trans*), 3.36 (d, J = 1.6 Hz, 1H *trans*, $CHCO_2t$-Bu), 3.71 (d, J = 4.8 Hz, 1H *cis*, $CHCO_2t$-Bu), 3.99 (d, J = 1.6 Hz, 1H *trans*, ArC*H*), 4.18 (d, J = 4.8 Hz, 1H *cis*, ArC*H*), 7.17−7.42 (m, 4H *cis* + *trans*, ArH).

Calcd for $C_{13}H_{15}ClO_3$ (254.72): C, 61.30; H, 5.94. Found: C, 61.15; H, 5.82.

***tert*-Butyl-3-(4-chlorophenyl)-oxirane-2-carboxylate (2d):**[5,11,16] white solid. Bp 118−125 °C/0.07 Torr or 126−131 °C/0.09 Torr (Kugelrohr).

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.21 (s, *t*-Bu, 9H *cis*), 1.51 (s, *t*-Bu, 9H *trans*), 3.35 (d, J = 1.6 Hz, 1H *trans*, $CHCO_2t$-Bu), 3.70 (d, J = 4.8 Hz, 1H *cis*, $CHCO_2t$-Bu), 3.99 (d, J = 1.6 Hz, 1H *trans*, ArC*H*), 4.17 (d, J = 4.8 Hz, 1H *cis*, ArC*H*), 7.20−7.38 (m, 4H *cis* + *trans*, ArH).

***tert*-Butyl 3-(4-methylphenyl)-oxirane-2-carboxylate (2e):**[5,6] white solid. Bp 104−106 °C/0.05 Torr or 109−112 °C/0.06 Torr (Kugelrohr).

(12) Jończyk, A.; Kwast, A.; Mąkosza, M. *J. Chem. Soc., Chem. Commun.* **1977**, 902–903.

(13) Achard, T. J. R.; Belokon, Y. N.; Hunt, J.; North, M.; Pizzato, F. *Tetrahedron Lett.* **2007**, *48*, 2961–2964.

(14) Shibata, I.; Yamasaki, H.; Baba, A.; Matsuda, H. *J. Org. Chem.* **1992**, *57*, 6909–6914.

(15) Baldoli, C.; Del Buttero, P.; Maiorana, S. *Tetrahedron* **1990**, *46*, 7823–7830.

(16) Bansal, R. K.; Sethi, K.; Bachelor, F. W. *Indian J. Chem.* **1980**, *19B*, 515–517.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.20 (s, *t*-Bu, 9H *cis*), 1.51 (s, *t*-Bu, 9H *trans*), 2.33 (s, 3H *cis*, C*H*$_3$Ar), 2.35 (s, 3H *trans*, C*H*$_3$Ar), 3.39 (d, J = 1.6 Hz, 1H *trans*, $CHCO_2t$-Bu), 3.69 (d, J = 4.8 Hz, 1H *cis*, $CHCO_2t$-Bu), 3.98 (d, J = 1.6 Hz, 1H *trans*, ArC*H*), 4.18 (d, J = 4.8 Hz, 1H *cis*, ArC*H*), 7.10−7.30 (m, 4H *cis* + *trans*, ArH).

***tert*-Butyl-3-(4-methoxyphenyl)-oxirane-2-carboxylate (2f):** yellow solidifying oil. Bp 123−128 °C/0.2 Torr or 101−108 °C/0.05 Torr (Kugelrohr).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.21 (s, *t*-Bu, 9H *cis*), 1.50 (s, *t*-Bu, 9H *trans*), 3.39 (d, J = 1.6 Hz, 1H *trans*, $CHCO_2t$-Bu), 3.67 (d, J = 4.4 Hz, 1H *cis*, $CHCO_2t$-Bu), 3.78 (s, 3H *cis*, CH_3O), 3.79 (s, 3H *trans*, CH_3O), 3.96 (d, J = 1.6 Hz, 1H *trans*, ArC*H*), 4.15 (d, J = 4.4, 1H *cis*, ArC*H*), 6.82−6.90 (m, 2H *cis* + *trans*, ArH), 7.17−7.34 (m, 2H *cis* + *trans*, ArH).

Calcd for $C_{14}H_{18}O_3$ (250.30): C, 67.18; H, 7.25. Found: C, 67.38; H, 7.37.

***tert*-Butyl-3-(4-cyanophenyl)-oxirane-2-carboxylate (2g):** yellowish solidifying oil. Bp 118−125 °C/0.06 Torr or 122−128 °C/0.07 Torr (Kugelrohr).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.18 (s, *t*-Bu, 9H *cis*), 1.51 (s, *t*-Bu, 9H *trans*), 3.35 (d, J = 1.6 Hz, 1H *trans*, $CHCO_2t$-Bu), 3.76 (d, J = 4.8 Hz, 1H *cis*, $CHCO_2t$-Bu), 4.06 (d, J = 1.6 Hz, 1H *trans*, ArC*H*), 4.24 (d, J = 4.8, 1H *cis*, ArC*H*), 7.38−7.70 (m, 4H *cis* + *trans*, ArH).

Calcd for $C_{14}H_{15}NO_3$ (245.28): C, 68.56; H, 6.16; N, 5.71. Found: C, 68.72; H, 6.19; N, 5.79.

***tert*-Butyl-3-(3-thiophen-3-yl)oxirane-2-carboxylate (2h):**[5,11] yellow oil. Bp 115−120 °C/0.08 Torr or 122−126 °C/0.11 Torr (Kugelrohr).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.26 (s, *t*-Bu, 9H *cis*), 1.50 (s, *t*-Bu, 9H *trans*), 3.49 (d, J = 1.6 Hz, 1H *trans*, $CHCO_2t$-Bu), 3.68 (d, J = 4.8 Hz, 1H *cis*, $CHCO_2t$-Bu), 4.08 (d, J = 1.6 Hz, 1H *trans*, ArC*H*), 4.20 (d, J = 4.8, 1H *cis*, ArC*H*), 6.96 (dd, J = 5.2, 1.2 Hz, 1H *trans*, ArH), 7.11 (dd, J = 5.2, 1.2 Hz, 1H *cis*, ArH), 7.25 (dd, J = 5.2, 2.8 Hz, 1H *cis*, ArH), 7.30 (dd, J = 5.2, 2.8 Hz, 1H *trans*, ArH), 7.32−7.34 (m, 1H *cis* + *trans*, ArH).

***tert*-Butyl-3-(1-naphthyl)oxirane-2-carboxylate (2i):**[6] yellowish solid. Bp 126−130 °C/0.05 Torr or 123−129 °C/0.05 Torr (Kugelrohr).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.90 (s, *t*-Bu, 9H *cis*), 1.58 (s, *t*-Bu, 9H *trans*), 3.43 (d, J = 1.6 Hz, 1H *trans*, $CHCO_2t$-Bu), 3.97 (d, J = 4.8 Hz, 1H *cis*, $CHCO_2t$-Bu), 4.67 (d, J = 1.6 Hz, 1H *trans*, ArC*H*), 4.69 (d, J = 4.8 Hz, 1H *cis*, ArC*H*), 7.45−8.06 (m, 7H *cis* + *trans*, ArH).

***tert*-Butyl-3-styryl-oxirane-2-carboxylate (2j):**[17] yellow oil (when mixture was rich in *trans*-diastereoisomer), white solid (when mixture was rich in *cis*-diastereoisomer). Bp 126−129 °C/0.08 Torr or 115−123 °C/0.06 Torr (Kugelrohr).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.50 (s, *t*-Bu, 9H *cis*), 1.51 (s, *t*-Bu, 9H *trans*), 3.39 (d, J = 2.0 Hz, 1H *trans*, $CHCO_2t$-Bu), 3.66 (d, J = 4.8 Hz, 1H *cis*, $CHCO_2t$-Bu), 3.69 (ddd, J = 8.0, 2.0, 0.8 Hz, 1H *trans*, ArC*H*), 3.75 (ddd, J = 8.4, 4.4, 0.4 Hz, 1H *cis*, ArH), 5.86 (dd, J = 16.0, 8.0 Hz, 1H *trans*, CH=CHC*H*), 6.16 (dd, J = 16.4, 8.4 Hz, 1H *cis*, CH=CHC*H*), 6.85 (d, J = 16.0, 1H *trans*, C*H*=CHCH), 6.88 (d, J = 16.4, 1H *cis*, C*H*=CHCH), 7.25−7.39 (m, 5H *cis* + *trans*, ArH).

***tert*-Butyl-3-(1-methylstyryl)-oxirane-2-carboxylate (2k).**[17] White solid. Bp 120−125 °C/0.05 Torr or 123−128 °C/0.06 Torr (Kugelrohr).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.40 (s, *t*-Bu, 9H *cis*), 1.52 (s, *t*-Bu, 9H *trans*), 1.74 (d, J = 2.0 Hz, 1H *trans*, CH=CC*H*$_3$), 1.93 (dd, J = 1.2, 0.4 Hz, 1H *cis*, CH=CC*H*$_3$), 3.42 (d, J = 1.6 Hz, 1H *trans*, $CHCO_2t$-Bu), 3.64 (d, J = 4.8 Hz, 1H *cis*, $CHCO_2t$-Bu), 3.67 (dd, J = 2.0, 0.4 Hz, 1H *trans*, ArC*H*), 3.68−3.70 (m, 1H *cis*, ArH), 6.63 (br s, 1H *cis*, C*H*=CCH$_3$), 6.72 (br s, 1H *trans*, C*H*=CCH$_3$), 7.20−7.38 (m, 5H *cis* + *trans*, ArH).

***tert*-Butyl-3-isopropyl-oxirane-2-carboxylate (2l):**[5] colorless oil (when mixture was rich in *trans*-diastereoisomer) or yellowish oil (when mixture was rich in *cis*-diastereoisomer). Bp 87−90 °C/0.15 Torr or 75−80 °C/0.11 Torr (Kugelrohr).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.91 (d, J = 6.8 Hz, 3H *cis*, (C*H*$_3$)$_2$CH), 0.97 (d, J = 6.8 Hz, 3H *trans*, (C*H*$_3$)$_2$CH), 1.00 (d, J = 6.8 Hz, 3H *trans*, (C*H*$_3$)$_2$CH), 1.11 (d, J = 6.8 Hz, 3H *cis*, (C*H*$_3$)$_2$CH), 1.46 (s, *t*-Bu, 9H *trans*), 1.47 (s, *t*-Bu, 9H *cis*), 1.56−1.68 (m, 1H *cis* + *trans*, (CH$_3$)$_2$C*H*), 2.78 (dd, J = 9.2, 4.8 Hz, 1H *cis*, (CH$_3$)$_2$CHC*H*), 2.89 (dd, J = 6.4, 2.0 Hz, 1H *trans*, (CH$_3$)$_2$CHC*H*), 3.11 (d, J = 2.0 Hz, 1H *trans*, $CHCO_2t$-Bu), 3.41 (d, J = 4.8 Hz, 1H *cis*, $CHCO_2t$-Bu).

***tert*-Butyl-3-(1-ethylpropyl)-oxirane-2-carboxylate (2m):**[5] colorless oil (when mixture was rich in *trans*-diastereoisomer) or yellowish oil (when mixture was rich in *cis*-diastereoisomer). Bp 101−105 °C/0.08 Torr or 92−95 °C/0.06 Torr (Kugelrohr).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.86 (t, J = 7.6 Hz, 3H *cis*, CH$_3$C*H*$_2$), 0.92 (t, J = 7.6 Hz, 3H *trans*, CH$_3$C*H*$_2$), 0.95 (t, J = 7.6 Hz, 3H *trans*, CH$_3$C*H*$_2$), 0.98 (t, J = 7.6 Hz, 3H *cis*, CH$_3$C*H*$_2$), 1.24−1.56 (m, 5H *cis* + *trans*, (CH$_3$C*H*$_2$)$_2$C*H*), 1.47 (s, *t*-Bu, 9H *trans*), 1.48 (s, *t*-Bu, 9H *cis*), 2.84 (dd, J = 8.0, 2.0 Hz, 1H *trans*, (CH$_3$CH$_2$)$_2$CHC*H*), 2.87 (dd, J = 8.8, 4.4 Hz, 1H *cis*, (CH$_3$CH$_2$)$_2$CHC*H*), 3.10 (d, J = 2.0 Hz, 1H *trans*, $CHCO_2t$-Bu), 3.39 (d, J = 4.4 Hz, 1H *cis*, $CHCO_2t$-Bu).

***tert*-Butyl-3-(1-cyclohexyl)-oxirane-2-carboxylate (2n):**[5,11] colorless oil (when mixture was rich in *trans*-diastereoisomer) or yellowish oil (when mixture was rich in *cis*-diastereoisomer). Bp 100−104 °C/0.10 Torr or 110−113 °C/0.15 Torr (Kugelrohr).

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.03−1.33 (m, 6 H, *c*-C$_6$H$_{11}$ *cis* + *trans*), 1.44 (s, *t*-Bu, 9H *trans*), 1.45 (s, *t*-Bu, 9H *cis*), 1.59−1.83 (m, 5 H, *c*-C$_6$H$_{11}$ *cis* + *trans*), 2.80 (dd, J = 9.2, 4.8 Hz, 1H *cis*, *c*-C$_6$H$_{11}$C*H*), 2.86 (dd, J = 6.8, 2.0 Hz, 1H *trans*, *c*-C$_6$H$_{11}$C*H*), 3.11 (d, J = 2.0 Hz, 1H *trans*, $CHCO_2t$-Bu), 3.37 (d, J = 4.8 Hz, 1H *cis*, $CHCO_2t$-Bu).

Received for review February 5, 2010.

OP1000379

(17) Gadaj, A.; Jończyk, A. *Synthesis* **2007**, 75–80.