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Palladium(0)-catalyzed asymmetric synthesis of 2-vinylmorpholine and 2-vinylpiperazine. Influence of the biscarbonate structure on the enantioselectivity

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Abstract

Palladium-catalyzed cyclization of *N*,*N*-bis(*p*-tolylsulfonyl)-*o*-phenylenediamine **2b** and 2-[(2,4,6-trimethylphenyl)sulfonyl]aminophenol **2c** with three allylic biscarbonates **1a**–**c** gave quite different enantioselectivities. This indicates that the cyclization processes do not have a common intermediate, as in the case of benzene-1,2-diol.

1. Introduction

Palladium-catalyzed cyclization processes are now widely used for the stereoselective synthesis of carbo- and heterocyclic systems, sometimes via cascade reactions.[1–8] We and others have recently described the palladium-catalyzed asymmetric synthesis of various 2-vinyldioxanes,[9] 2-vinylmorpholines,[10–12] and 2-vinylpiperazines,[10,13,14] starting from benzene-1,2-diol, 2-aminophenol, and 1,2-diaminobenzene, respectively, and 1,4-bis(methoxycarbonyloxy)but-2-ene. Although the allylic biscarbonate normally used had *Z* stereochemistry, benzene-1,2-diol was also condensed with the *E* stereoisomer. Since the same enantioselectivities were observed in both cases, it was assumed that the *syn–anti* isomerization of the π-allyl palladium intermediate obtained by the first nucleophilic substitution of the *E* or *Z* biscarbonate was fast compared to the attack of the second nucleophile. We wish to report our studies on the use of (*Z*)- and (*E*)-1,4-bis(methoxycarbonyloxy)but-2-ene and 3,4-bis(methoxycarbonyloxy)but-1-ene in this cyclization reaction, and the important role played by the substituents at the nitrogen on the enantioselectivity of this reaction.

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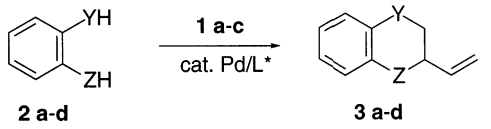
2. Results and discussion

The reaction of benzene-1,2-diol **2a**, *N*,*N*-bis(*p*-tolylsulfonyl)-*o*-phenylenediamine **2b** and 2-[(2,4,6-trimethylphenyl)sulfonyl]aminophenol **2c** with the three allylic biscarbonates **1a–c** (Scheme 1) was carried out in THF at room temperature in the presence of a palladium complex generated in situ by mixing $Pd_2(dba)_3$ with the chiral ligand. The results are summarized in Table 1.

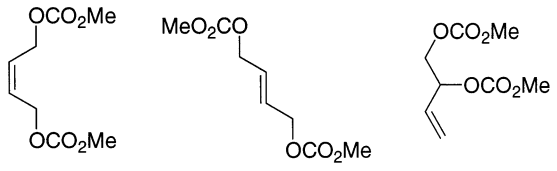


2 a-d **3 a-d**

a : Y = Z = O; **b** : Y = Z = $NSO_2C_6H_4$-*p*-CH_3

c : Y = $NSO_2C_6H_2$-2,4,6-triCH_3, Z = O

d : Y = $NCH_2C_6H_5$; Z = O



1a **1b** **1c**

Scheme 1.

Table 1
Palladium-catalyzed asymmetric synthesis of compounds **3** from **1** and **2**[a]

Entry	Substrate **2**	Carbonate **1**	Ligand	Product	Yield[b] (%)	E.e.[c] (%) (config.)
1	**2a**	**1a**	(*R*)-Binap	**3a**	60	37 (*R*)
2	**2a**	**1b**	(*R*)-Binap	**3a**	60	37 (*R*)
3	**2a**	**1c**	(*R*)-Binap	**3a**	60	37 (*R*)
4	**2b**	**1a**	(*S*)-MeOBiphep	**3b**	50	52 (*R*)
5	**2b**	**1b**	(*S*)-MeOBiphep	**3b**	20	37 (*R*)
6	**2b**	**1c**	(*S*)-MeOBiphep	**3b**	17	48 (*R*)
7	**2c**	**1a**	(*S*)-MeOBiphep	**3c**	52	64 (*S*)
8	**2c**	**1c**	(*S*)-MeOBiphep	**3c**	12	18 (*S*)
9	**2d**	**1a**	(*S*)-MeOBiphep	**3d**	95	38 (*S*)
10	**2d**	**1c**	(*S*)-MeOBiphep	**3d**	93	46 (*S*)

[a] All entries carried out under N_2 for 24 h in THF at 25°C in the presence of a palladium catalyst prepared in situ by mixing $Pd_2(dba)_3$ (2.5 mol% Pd) and the chiral ligand (Pd]/[P] = 1:2).

[b] Isolated yields after silica gel chromatography and not optimized.

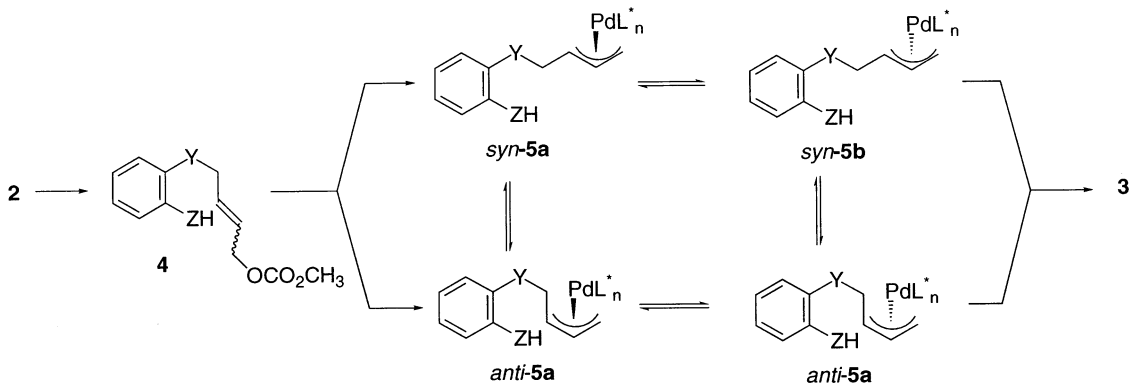
[c] Determined by GC analysis (Chiraldex Column, type B-PH) for **3a**, HPLC analysis (Chiralpak AD) for **3b** and **3c**, and based on specific rotation for **3d**.[13]

Reaction of benzene-1,2-diol **2a** with carbonates **1a–c** in the presence of palladium(0) associated with (*R*)-Binap as the chiral ligand gave the same enantioselectivity (37%) and chemical yield (60%) for compound **3a**, whatever the carbonate used (Table 1, entries 1–3).

N,*N*-Bis(*p*-tolylsulfonyl)-*o*-phenylenediamine **2b** reacted with carbonates **1a**, **1b** and **1c** in the presence of (*S*)-MeOBiphep as the chiral ligand, to give the 1,2,3,4-tetrahydro-2-vinylquinoxaline **3b** in 52, 37 and 48% e.e., respectively (Table 1, entries 4, 5 and 6), and 50, 20 and 17% yield. More importantly, condensation of 2-[(2,4,6-trimethylphenyl)sulfonyl]aminophenol **2c** with carbonates **1a** and **1c**, in the presence of the same ligand, gave the 3,4-dihydro-2-vinyl-1,4-benzoxazine **3c** with quite different enantioselectivities and yields: in the presence of carbonate **1a**, compound **3c** was obtained with 64% e.e. and 52% yield (Table 1, entry 7), whereas with carbonate **1c**, **3c** was obtained with quite low e.e. (only 18%) and chemical yield (12%) (Table 1, entry 8).

Finally, condensation of *N*-benzyl-2-aminophenol **2d** with carbonates **1a** or **1c** in the presence of (*S*)-MeOBiphep gave 2-vinyl-1,5-benzoxazine **3d** with 38 and 46% e.e. (Table 1, entries 9 and 10).

A plausible reaction pathway for the cyclization is shown in Scheme 2. The first nucleophilic allylic substitution on the π-allyl palladium complex generated by the reaction of the biscarbonate with a palladium(0) species takes place with the hydroxyl group in **2a** or the amino group in **2b–c** to give an allylic carbonate **4**. This intermediate reacts with palladium(0) to give a new π-allyl palladium intermediate **5**; intramolecular attack of the hydroxyl or the amino group on this π-allyl produces the cyclized compound **3**.



Scheme 2.

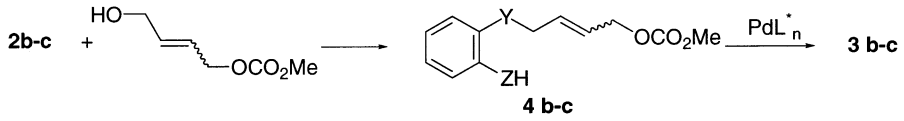
One of the problems in this cyclization sequence is the determination of the enantioselective step. If the interconversion between the four possible diastereoisomeric π-allyl palladium complexes **5** is fast compared with the cyclization reaction, then the enantioselectivity will be determined by the stabilities of these diastereomeric complexes and their relative rate of cyclization. However, if this interconversion is slow compared with the cyclization reaction, then the enantioselectivity could be determined by the ability of the catalyst to differentiate the two enantiotopic faces of compound **4**. However, this implies that the palladium dissociates from the double bond to give free compound **4** as an intermediate, before association and oxidative addition to give intermediates **5**. If the dissociation of the palladium from the double bond of intermediate **4** is slow compared with the oxidative addition of the carbonate, then the enantioselectivity could be determined, at least partly, by the discrimination of the double bond for carbonate **1b**. The low chemical yields observed starting from **1c** could be due to some kinetic resolution.

Since the same enantioselectivity was obtained in the cyclization of benzene-1,2-diol **2a** with carbonates **1a–c** whatever the carbonate used, this indicates that intermediate **4a** is probably the same, starting from each carbonate, and that the equilibrium between the diastereomeric complexes is fast compared with the cyclization reaction in this case.[15] The same behavior was observed for the condensation of *N*-benzyl-2-aminophenol **2d** with carbonates **1a** and **1c**.

Conversely, quite different enantioselectivities were obtained in the condensation of *N*,*N*-bis(*p*-tolylsulfonyl)-*o*-phenylenediamine **2b** or 2-[(2,4,6-trimethylphenyl)sulfonyl]aminophenol **2c** with these carbonates; this is an indication that in these cases the enantioselectivity is probably not only due to the differentiation of the two enantiotopic faces of intermediates **4b–c** by the chiral catalyst, and that the structure of the starting biscarbonate as well as the sulfonyl group probably has some influence on both the enantioselectivity and the chemical yield of the cyclization reaction.

In order to have more information about the reasons for these quite different enantioselectivities, we prepared the intermediates **4b–c** of configuration *Z* and *E*, and submitted them to the cyclization conditions.

Compounds **4b–c** were prepared via a Mitsunobu coupling reaction between the monocarbonate of butene-1,4-diol of configuration *E* or *Z* and the corresponding 2-(arylsulfonylamino)phenol **2b**, or bis(arylsulfonylamino)benzene **2c**, respectively (Scheme 3). No isomerization of the double bond of the olefins was observed. The stereochemistry of this double bond was unambiguously assigned by ^{13}C NMR spectroscopy. For compound **4b**, we observed the $-OCH_2-$ signals at δ 62.6 and 66.9 ppm for the (*Z*)- and (*E*)-isomers, respectively, and the $-NCH_2-$ signals at δ 48.8 and 53.6 ppm, respectively, in agreement with this stereochemistry. The $-OCH_2-$ signals for (*Z*)-**4c** and (*E*)-**4c** are at δ 63.5 and 67.1 ppm, and the $-NCH_2-$ signals appeared at δ 48.2 and 52.4 ppm, respectively.



Scheme 3. **b**: $Y=Z=NSO_2C_6H_4$-*p*-CH_3; **c**: $Y=NSO_2C_6H_2$-2,4,6-triCH_3; $Z=O$

The cyclization reaction was carried out as previously described and the results are summarized in Table 2. The cyclization of compounds (*E*)-**4b** and (*Z*)-**4b** gave 1,2,3,4-tetrahydro-2-vinylquinoxaline **3b** in 45 and 17% yield, respectively, with enantioselectivities of up to 18% (*R*)

Table 2
Palladium-catalyzed cyclization of compounds **4**[a]

Entry	Compound	Product	Ligand	Yield[b] (%)	E.e.[c] % (config.)
1	(*E*)-**4b**	**3b**	(*S*)-MeOBiphep	45	18 (*R*)
2	(*Z*)-**4b**	**3b**	(*S*)-MeOBiphep	17	9 (*R*)
3	(*E*)-**4c**	**3c**	(*S*)-MeOBiphep	53	16 (*S*)
4	(*Z*)-**4c**	**3c**	(*S*)-MeOBiphep	21	28 (*R*)

[a] All entries carried out under N_2 for 24 h in THF at 25°C in the presence of a palladium catalyst prepared in situ by mixing $Pd_2(dba)_3$ (2.5 mol% Pd) and the chiral ligand (Pd]/[P]=1:2).

[b] Isolated yields after silica gel chromatography and not optimized.

[c] Determined by HPLC analysis (Chiralpak AD) for **3b–c**.

and 9% (*R*), respectively (Table 2, entries 1 and 2); it is to be noticed that these enantioselectivities are lower than those obtained by the direct condensation of *N*,*N*-bis(*p*-tolylsulfonyl)-*o*-phenylenediamine **2b** with carbonates **1a**–**c**. When the cyclization was performed on compounds (*E*)-**4c** and (*Z*)-**4c**, 3,4-dihydro-2-vinyl-1,4-benzoxazine **3c** was obtained in 53 and 21% yield, respectively (Table 2, entries 3 and 4); however, the (*E*) isomer gave the (*S*) enantiomer in 16% e.e., although the (*Z*) isomer gave the (*R*) enantiomer in 28% e.e.

The results obtained starting from intermediates **4** deserve some comments. In the case of intermediates **4b** and **4c**, the cyclization of the two stereoisomers led to different enantioselectivities, and even for **4c**, to the opposite configuration for the cyclized product **3c**. So, in these cases, the asymmetric induction derives from the chiral recognition of the enantiotopic faces of the substrate **4b** or **4c** during the formation of the π-allyl palladium complex; moreover, the interconversion of the diastereoisomeric π-allyl palladium complexes is necessarily slow compared with the cyclization reaction. We also noticed that the intermolecular reaction between **2b**–**c** and **1** leading to **3b**–**c** gave higher enantioselectivities in the (*R*) enantiomer than starting from the intermediate **4b**–**c**. This difference in enantioselectivity implies that, in these two cases, there is probably no dissociation of the palladium complex, after the first nucleophilic allylic substitution of the amino group on the π-allyl palladium complex generated by the reaction of the biscarbonate with a palladium(0) species. This very low interconversion between the diastereoisomeric π-allyl palladium complexes as well as the non-dissociation of the palladium complex from intermediate **4** is probably due to the presence of the sulfonyl group, which could coordinate to the palladium complex. The same enantioselectivities obtained in the condensation of *N*-benzyl-2-aminophenol **2d** are in agreement with this hypothesis.

3. Conclusion

In conclusion, we have shown that the asymmetric cyclization between various allylic biscarbonates and various aminophenols or diaminobenzenes depends strongly on the stereochemistry of the biscarbonate as well as on the substituents of the nitrogen. We assumed that the sulfonyl groups probably coordinate to the palladium complex during the catalytic cycle, and that there is no common intermediate for these cyclizations.

4. Experimental

4.1. General

^{1}H NMR (200 MHz) and ^{13}C NMR (50 MHz) spectra were obtained using a Brüker AM 200 spectrometer. Chemical shifts are reported on the δ scale with reference to tetramethylsilane as an internal standard. Silica gel column chromatography was carried out using Merck silica gel 60 Gerudan (40–63 μm). GC analyses were recorded with a Shimadzu capillary gas chromatograph equipped with a Chiraldex™, type B-PH (30 m×0.32 mm) capillary column. Analytical HPLC was performed using a Shimadzu instrument with a UV detector and equipped with a Chiralpak AD column (eluent: *n*-hexane/2-propanol, 80:20). Reactions involving organometallic catalysis were carried out in Schlenk tubes under an inert atmosphere. Tetrahydrofuran was distilled from sodium/benzophenone. The following compounds were prepared according to

literature procedures: (*Z*)- and (*E*)-1,4-bis(methoxycarbonyloxy)but-2-ene **1a** and **1b**,[16] 3,4-bis-(methoxycarbonyloxy)but-1-ene **1c**,[16] *N*,*N*-bis(*p*-tolylsulfonyl)-*o*-phenylenediamine **2b**,[17] *N*-benzyl-2-aminophenol **2d**.[18] (*S*)-6,6′-Dimethoxy-2,2′-bis(diphenylphosphanyl)-1,1′-biphenyl (MeOBiphep) was a gift from Dr. Schmid (Hofmann La Roche, Basle, Switzerland).

4.2. 2-[(2,4,6-Trimethylphenyl)sulfonyl]aminophenol **2c**

To a solution of 2-aminophenol (545 mg, 5 mmol) and C_5H_5N (435 mg, 5.5 mmol) in CH_2Cl_2 (5 mL) at 0°C was slowly added 2,4,6-trimethylphenylsulfonyl chloride (1.2 g, 5.5 mmol). After 24 h at room temperature, H_2O (2 mL) was added; separation of the organic phase followed by evaporation of the solvent and recrystallization in ethanol afforded 658 mg of compound **2c** (yield 45%). Mp: 112–113°C. ^{1}H NMR ($CDCl_3$): δ 2.23 (s, 3H, Me), 2.58 (s, 6H, Me), 6.72–6.84 (m, 2H, H_{ar}), 6.90–6.98 (m, 3H, H_{ar}), 7.19 (dd, *J* 7.9 and 1.6 Hz, 1H, H_{ar}), 8.31 (bs, 2H, OH, NH). ^{13}C ($CDCl_3$): δ 21.1 (Me), 23.2 (Me), 117.0, 121.0, 122.7, 125.5, 128.3, 132.2, 132.5, 139.8, 143.1 and 151.0 (C_{ar}). Anal. calcd for $C_{15}H_{17}NO_3S$ (294.37): C, 61.84; H, 5.88. Found: C, 61.56; H, 5.83.

4.3. General procedure for the preparation of compounds **4**

To a mixture of **2b–c** (0.69 mmol), (*Z*)- or (*E*)-4-(methoxycarbonyloxy)but-2-enol (100 mg, 0.69 mmol), and diethyl azodicarboxylate (120 mg, 0.69 mmol) in THF (8 mL) was added at 0°C triphenylphosphine (181 mg, 0.69 mmol). After being stirred for 12 h at room temperature, the solvent was evaporated. Chromatography of the residue on silica gel gave compound **4**.

4.3.1. (Z)-4-[N-*Tosyl*-N-*(2-tosylaminophenyl)]amino-1-(methoxycarbonyloxy)but-2-ene* (Z)-**4b**

Yield 49%; R_f 0.62 (eluent: petroleum ether/ethyl acetate, 1:1). ^{1}H NMR ($CDCl_3$): δ 1.6 (bs, 1H, NH), 2.38 (s, 3H, Me), 2.44 (s, 3H, Me), 3.74 (s, 3H, OMe), 4.22–4.36 (m, 4H, CH_2), 5.20–5.42 (m, 2H, –CH=), 6.17–7.29 (m, 4H, H_{ar}), 7.45 (d, *J* 8.3 Hz, 2H, H_{ar}), 7.62 (d, *J* 8.3 Hz, 2H, H_{ar}), 7.83 (d, J 8.3 Hz, 4H, H_{ar}). ^{13}C ($CDCl_3$) δ 21.6 (Me), 48.8 (CH_2N), 54.9 (OMe), 62.6 (CH_2O), 120.2, 123.9, 127.4, 127.8, 128.3, 128.7, 129.6, 129.7, 133.4, 136.9, 137.1, 144.0, 144.6 (–CH=, C_{ar}), 155.5 (CO).

4.3.2. (E)-4-[N-*Tosyl*-N-*(2-tosylaminophenyl)]amino-1-(methoxycarbonyloxy)but-2-ene* (E)-**4b**

Yield 51%; R_f 0.62 (eluent: petroleum ether/ethyl acetate, 1:1). ^{1}H NMR ($CDCl_3$) δ 1.5 (bs, 1H, NH), 2.39 (s, 3H, Me), 2.44 (s, 3H, Me), 3.75 (s, 3H, OMe), 4.05–4.37 (m, 4H, CH_2), 5.32–5.46 (m, 2H, –CH=), 6.17–7.29 (m, 4H, H_{ar}), 7.45 (d, *J* 8.3 Hz, 2H, H_{ar}), 7.62 (d, *J* 8.3 Hz, 2H, H_{ar}), 7.83 (d, *J* 8.3 Hz, 4H, H_{ar}). ^{13}C ($CDCl_3$) δ 21.5 (Me), 21.6 (Me), 53.6 (CH_2N), 54.9 (OMe), 66.9 (CH_2O), 120.1, 123.8, 127.5, 128.2, 128.4, 128.6, 129.3, 129.5, 129.7, 133.7, 137.0, 144.0, 144.5 (–CH=, C_{ar}), 155.4 (CO).

4.3.3. (Z)-4-[N-*(2-Hydroxyphenyl)*-N-*(2,4,6-trimethylphenyl)sulfonyl]amino-1-(methoxycarbonyl-oxy)but-2-ene* (Z) **4c**

Yield 42%; R_f 0.31 (eluent: petroleum ether/ethyl acetate, 3:1). ^{1}H NMR ($CDCl_3$) δ 2.20 (s, 3H, Me), 2.32 (s, 6H, 2×Me), 3.67 (s, 3H, OMe), 4.33–4.47 (m, 4H, CH_2), 5.57–5.60 (m, 2H,

–CH=), 6.57–6.63 (m, 2H, H_{ar}), 6.80–6.92 (m, 3H, H_{ar}), 7.07–7.28 (m, 1H, H_{ar}), 7.19 (s, 1H, OH). ^{13}C ($CDCl_3$) δ 21.7 (Me), 23.8 (2×Me), 48.2 (CH_2N), 55.6 (OMe), 63.5 (CH_2O), 118.9, 121.8, 125.5, 128.7, 129.4, 131.0, 131.3, 132.8, 141.1, 143.9, 149.0, 155.7 (–CH=, C_{ar}), 156.2 (CO). Anal. calcd for $C_{21}H_{25}NO_6S$ (419.49): C, 60.13; H, 6.01. Found C, 59.65; H, 6.13.

*4.3.4. (*E*)-4-[*N*-(2-Hydroxyphenyl)-*N*-(2,4,6-trimethylphenyl)sulfonyl]amino-1-(methoxycarbonyloxy)but-2-ene (*E*) **4c***

Yield 45%; R_f 0.31 (eluent: petroleum ether/ethyl acetate, 3:1). ^1H NMR ($CDCl_3$) δ 2.26 (s, 3H, Me), 2.39 (s, 3H, Me), 2.52 (s, 3H, Me), 3.75 (s, 3H, OMe), 4.33–4.47 (m, 4H, CH_2), 5.58–5.74 (m, 2H, –CH=), 6.47–7.33 (m, 7H, OH, H_{ar}). ^{13}C ($CDCl_3$) δ 21.0 (Me), 23.0 (2×Me), 52.4 (CH_2N), 54.9 (OMe), 67.1 (CH_2O), 116.6, 120.7, 122.9, 124.8, 127.7, 128.8, 130.4, 132.0, 139.6, 140.3, 142.8, 143.2, 150.4 (–CH=, C_{ar}), 154.8 (CO).

4.4. General procedure for the cyclization reaction

A solution of tris(dibenzylideneacetone)dipalladium (5.8 mg, 6.3×10^{-3} mmol) and the chiral ligand (12.5×10^{-3} mmol) in 3 mL of THF was stirred at room temperature for 30 min. To the solution were added the substrate **2** (0.25 mmol) and the biscarbonate **1** (0.35 mmol), or compound **4** (0.25 mmol), dissolved in 3 mL of THF. The mixture was stirred at room temperature for 24 h. The solution was concentrated under reduced pressure and the residue was chromatographed on silica gel to give the cyclized product **3**. The enantioselectivity was determined by GPC analysis using a chiral stationary phase column Chiraldex™ type B-PH (30 m×0.32) at 85°C for compound **3a**,[9] by HPLC analysis with a chiral stationary phase column (Chiralpax AD, eluent: *n*-hexane/2-propanol, 80:20) for compounds **3b**–**c**, according to the procedure previously described.[12,14]

*4.4.1. 4-(2,4,6-Trimethylphenyl)sulfonyl-2-vinyl-3,4-dihydro-2*H*-1,4-benzoxazine **3c***

Oil; R_f 0.77 (eluent: petroleum ether/ethyl acetate, 4:1); $[\alpha]_D^{20}=-27.8$ (*c* 2, $CHCl_3$) (64% e.e.). ^1H NMR ($CDCl_3$) δ 2.33 (s, 3H, Me), 2.57 (s, 6H, Me), 3.12 (dd, *J* 14.3 and 9.6 Hz, 1H, H-3_a), 4.12 (dd, *J* 14.3 and 2.5 Hz, 1H, H-3_{eq}), 4.50–4.58 (m, 1H, H-2), 5.34 (dd, *J* 10.5 and 1.1 Hz, 1H, =CH_2),), 5.43 (dd, *J* 17.3 and 1.4 Hz, 1H, =CH_2), 5.87 (ddd, *J* 17.3, 10.5 and 5.9 Hz, 1H, –CH=), 6.74–6.82 (m, 1H, H_{ar}), 6.92–7.09 (m, 5H, H_{ar}). ^{13}C ($CDCl_3$) δ 21.8 (Me), 23.7 (2×Me), 48.0 (CH_2N), 74.7 (CHO), 118.4, 119.6, 121.3, 124.5, 124.9, 126.9, 133.2, 134.4, 134.5, 140.9, 144.1, 148.1 (–*C*H=*C*H_2, C_{ar}). Anal. calcd for $C_{19}H_{21}NO_3S$ (343.37): C, 66.44; H, 6.16. Found: C, 66.21; H, 6.35.

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References

1. (a) Oppolzer, W. *Angew. Chem., Int. Ed. Engl.* **1989**, *28*, 38–52. (b) Oppolzer, W. In *Comprehensive Organic Synthesis;* Trost, B. M.; Fleming, I.; Paquette, L. A., Eds.; Pergamon Press: Oxford, 1991; Vol. 5, pp. 29–61.

2. Grigg, R. *J. Heterocycl. Chem.* **1994**, *31*, 631–639.
3. De Meijere, A.; Meyer, F. E. *Angew. Chem., Int. Ed. Engl.* **1994**, *33*, 2379–2411.
4. Thebtaranonth, C.; Thebtaranonth, Y. *Cyclization Reactions*; CRC Press: London, 1994; pp. 255–330.
5. Tietze, L. F. *Chem. Ind. (London)* **1995**, 453–457.
6. (a) Heumann, A.; Reglier, M. *Tetrahedron* **1995**, *51*, 975–1015. (b) **1996**, *52*, 9289–9346.
7. Negishi, E.; Coperet, C.; Ma, S.; Liou, S. Y.; Lin, F. *Chem. Rev.* **1996**, *96*, 365–393.
8. Ojima, I.; Tzamarioudaki, M.; Li, Z.; Donovan, R. J. *Chem. Rev.* **1996**, *96*, 635–662.
9. (a) Massacret, M.; Goux, C.; Lhoste, P.; Sinou, D. *Tetrahedron Lett.* **1994**, *35*, 6093–6096. (b) Massacret, M.; Lhoste, P.; Lakhmiri, R.; Parella, T.; Sinou, D. *Eur. J. Org. Chem.* **1999**, 2665–2673.
10. Uozomi, T.; Tanahashi, A.; Hayashi, T. *J. Org. Chem.* **1993**, *58*, 6826–6832.
11. Yamazaki, A.; Achiwa, I.; Achiwa, K. *Tetrahedron*: *Asymmetry* **1996**, *7*, 403–406.
12. Lhoste, P.; Massacret, M.; Sinou, D. *Bull. Soc. Chim. Fr.* **1997**, *134*, 343–347.
13. Yamazaki, A.; Achiwa, K. *Tetrahedron*: *Asymmetry* **1995**, *6*, 1021–1024.
14. Massacret, M.; Lhoste, P.; Sinou, D. *Eur. J. Org. Che*m. **1999**, 129–134.
15. (a) Trost, B. M.; Krische, M. J.; Radinov, R.; Zanoni, G. *J. Am. Chem. Soc.* **1996**, *118*, 6297–6298. (b) Pfaltz, A.; Roch, G. *Tetrahedron: Asymmetry* **1996**, *7*, 2213–2216. (c) Trost, B. M.; Asakawa, N. *Synthesis* **1999**, 1491–1494.
16. Tsuda, T.; Kioy, T.; Saegusa, T. *J. Org. Chem.* **1990**, *55*, 3388–3390.
17. Amundsen, L. H. *J. Am. Chem. Soc.* **1937**, *59*, 1466–1467.
18. Boothroy, B.; Clark, E. R. *J. Chem. Soc.* **1953**, 1499–1504.