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Synthesis and photooxygenation of (*S*)-*p*-tolylsulfinylfuran derivatives

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Abstract

The synthesis of different (*S*)-1,4-dicarbonyl-2-(*p*-tolylsulfinyl)-2-alkenes by photooxygenation of enantiomerically pure (*S*)-*p*-tolylsulfinylfurans is reported. © 2000 Published by Elsevier Science Ltd. All rights reserved.

1. Introduction

Substituted furans are key architectural features in a wide range of natural products[1] and have been frequently used in organic synthesis[2] as versatile building blocks. One of their most useful transformations is the oxidative ring opening[3] giving rise to 1,4-dicarbonyl compounds which can be further transformed into complex molecules taking advantage of their high reactivity as dienophiles and Michael acceptors. Applications in asymmetric synthesis require the accessibility of enantiomerically pure derivatives.[4] In connection with a program directed to developing new applications of sulfoxides,[5,6] we reasoned that introduction of an enantiopure sulfinyl group into the furan ring would allow access to chiral sulfinyl substituted 1,4-diketo derivatives.[7] Therefore, we focused on *p*-tolylsulfinylfurans **1** as a source of sulfinyl derivatives bearing 1,4-dicarbonyl-2-alkenes such as **2** (Fig. 1) which could be obtained by oxidative ring opening of the former compounds.

Although some sulfinylfuran derivatives that could act as dienes in Diels–Alder reactions are known,[8] their use in asymmetric synthesis has been rare probably as a consequence of the inherent difficulties encountered in the synthesis of such differently substituted chiral targets. A few recent reports have revealed the ability of some sulfinylfuryl carboxaldehydes to behave as chiral heterodienophiles[9] and, when supporting an α,β-unsaturated ketone, as dienophiles.[8a] A bibliographic

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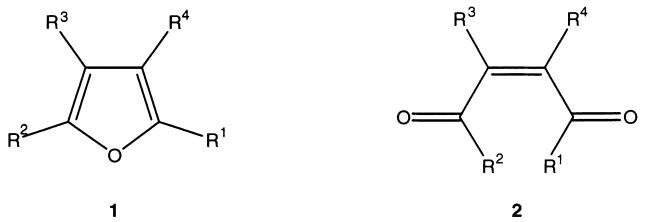


1 2

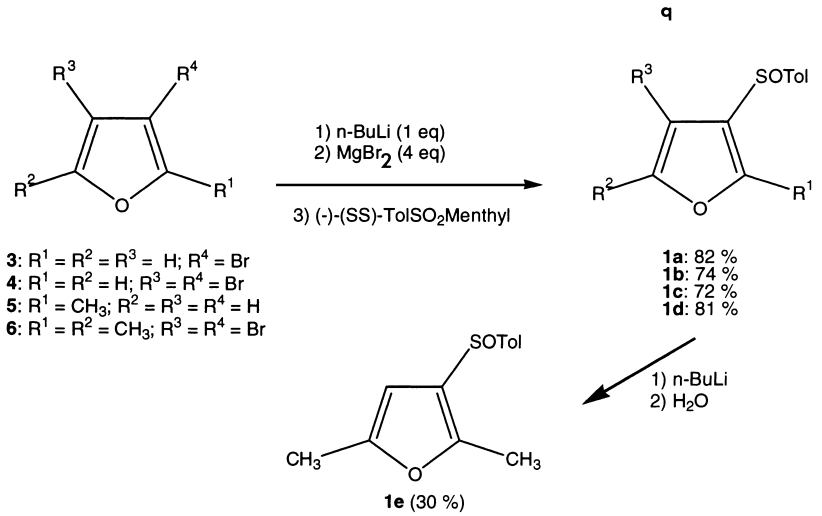
	R^1	R^2	R^3	R^4
a	H	H	H	SOp-Tol
b	H	H	Br	SOp-Tol
c	SOp-Tol	CH_3	H	H
d	CH_3	CH_3	Br	SOp-Tol
e	CH_3	CH_3	H	SOp-Tol

Figure 1.

search of compounds of type **2**, revealed no reports of such highly functionalized analogues. The wide interest in both families of compounds prompted us to undertake their synthesis. We report herein a regiocontrolled approach to enantiomerically pure *p*-tolylsulfinylfurans **1a**–**e** and the study of their sensitized photooxygenation as a direct access to compounds of type **2**.

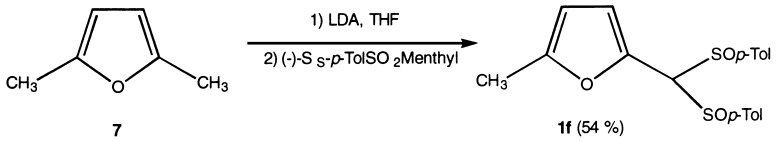
2. Results and discussion

The simplest and most widely used approach to enantiomerically pure sulfoxides is Andersen's synthesis[10] based on the reaction of an organometallic species with menthyl *p*-toluenesulfinate. Application of this procedure for the preparation of *p*-tolylsulfinylfurans involves the regiocontrolled formation of metallated furan precursors. Although regioselective directed metallation of furans is highly dependent on the substitution on the aromatic ring as well as on experimental conditions,[11] preferred reaction occurs at C-2 when it is unsubstituted. The synthesis of 3-sulfinyl substituted derivatives was then planned starting from the corresponding 3-bromofurans to allow the selective formation of the required 3-metallated species through a Br metal exchange. Compound **1a**[8b] had already been obtained following this methodology from 3-bromofuran **3**. When we applied the reported procedure for 3-(*p*-tolylsulfinyl)furan **1a** generating the organolithium intermediate by addition of 3-bromofuran **3** to a stirred solution of *n*-BuLi, and subsequent addition of $MgBr_2{\cdot}Et_2O$ and (S*S*)-menthyl-*p*-toluenesulfinate,[12] 3-bromo-2-(*p*-tolylsulfinyl)-furan[8b] was obtained in a 73% yield. Enantiomerically pure derivative **1a** (Scheme 1) could be synthesized in 82% yield applying a slight modification of this procedure: addition of the *n*-BuLi solution to the bromo derivative **3** to generate the organolithium (see Experimental). (S*S*)-4-Bromo-3-(*p*-tolylsulfinyl)furan **1b** was prepared in a highly regiocontrolled manner by successive treatment of 3,4-dibromofuran **4**[13] with *n*-BuLi (1 equiv.), an excess of $MgBr_2$ (4 equiv.) and (−)-(S*S*)-menthyl-*p*-toluenesulfinate at −78°C (Scheme 1). Under these conditions, **1b** was isolated after flash chromatography in a 74% yield and in enantiomerically pure form.[14] Synthesis of **1c**[15] was similarly achieved in 72% yield starting from 2-methylfuran **5**. As previously observed by us[16] and corroborated by other authors,[8c] the use of $MgBr_2$ is essential to avoid partial racemization of the final sulfoxide that sometimes occurred when the initially formed organolithium reagent directly reacted with the sulfinylating agent.



Scheme 1.

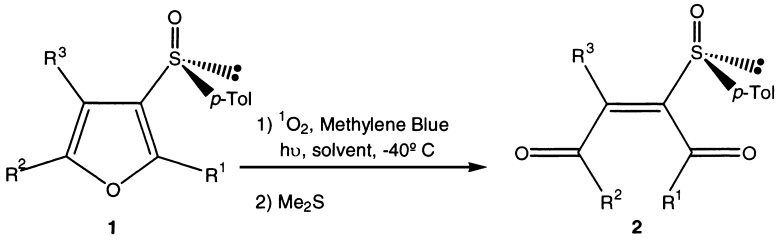
In a similar way, 3,4-dibromo-2,5-dimethyl furan **6**[17] afforded enantiomerically pure (S*S*)-4-bromo-2,5-dimethyl-3-(*p*-tolylsulfinyl)furan **1d** in a 81% yield. Further debromination of **1d**, that was achieved after *n*-BuLi/bromo exchange by adding water, provided (S*S*)-2,5-dimethyl-3-(*p*-tolylsulfinyl)furan **1e** in a 30% yield. The moderate yield of this reaction was due to the competitive formation of *n*-butyl-*p*-tolyl sulfoxide[18] that was isolated in a 23% yield. This sulfoxide could only be formed in a nucleophilic attack of *n*-BuLi to the sulfinyl group of the furan ring of **1d** and/or **1e**. In order to improve the yield of **1e**, we attempt to introduce the sulfinyl group at C-3 by direct metallation of 2,3-dimethylfuran **7** (Scheme 2). In all trials, (S*S*,S*S*)-2-(1,1′-bis-*p*-tolylsulfinyl)methyl-5-methylfuran **1f** was formed and no traces of **1e** were detected. The best yield of **1f** (54%) was achieved by sequentially adding 2,5-dimethylfuran **7** in THF and the sulfinylating agent over a solution of LDA.



Scheme 2.

Transformation of compounds **1** into 1,4-dicarbonyl alkenyl sulfoxides **2** had to take into account the presence of the sulfinyl group which is sensitive to oxidation. Among the wide range of procedures reported to oxidize the furan ring,[3] we first tried Br_2 in the presence of pyridine.[19] We investigated the behaviour of 4-bromo-2,5-dimethyl-3-(*p*-tolylsulfinyl)furan **1d** in order to find the best conditions to isolate the presumably more stable 1,4-diketone **2d**. Unfortunately, all the experiments effected with this oxidizing reagent using different solvents (acetone:H_2O, CH_3CN:H_2O, MeOH) were unsuccessful, in that the starting material decomposed to a complex reaction mixture. The use of $^1O_2$[3b–d,20] and methylene blue as sensitizer, working under very mild conditions (MeOH as solvent), gave rise, after treatment with Me_2S, to a clean reaction mixture

where (*Z*,S*S*)-4-bromo-3-(*p*-tolylsulfinyl)-3-hexen-2,5-dione **2d** and DMSO were the only products detected (Scheme 3). The use of MeOH as solvent promoted the transformation of the initial endoperoxide to a new intermediate hydroperoxide[21] which is stable at low temperature and allowed the formation of *cis*-1,4-dicarbonyl compound[3a] in the presence of Me_2S.



solvent	yield (%)
CH_2Cl_2	**2a** : (84)
MeOH	**2d** : (94)
MeOH	**2e** : (86)

Scheme 3.

The reaction of (S*S*)-3-(*p*-tolylsulfinyl)-2,5-dimethylfuran **1d** in similar conditions allowed the isolation of (*E*,S*S*)-3-(*p*-tolylsulfinyl)-3-hexen-2,5-dione **2d** in 86% yield. Dialdehyde **2a** resulting from the photooxidation of **1a** could be generated using CH_2Cl_2 as solvent since in the presence of MeOH a complex reaction mixture was formed. Compound **2a** was characterized from the crude reaction mixture that revealed the clean formation of **2a** and DMSO. Dialdehyde **2a** could not be purified by chromatography due to its easy decomposition in the presence of silica gel.[22] The stereochemistry of the double bonds of **2a**, **2d** and **2e** was assigned as indicated in Scheme 3 from the accepted mechanism of these processes. [3a] When photosensitized oxidations were carried out on **1b**, **1c** and **1f** under the same conditions as above, a complex reaction mixture resulted after the starting materials had disappeared. The use of different solvents (MeOH, CH_2Cl_2) and temperatures did not result in the presence of compounds **2b**, **2c** and **2f** being detected in the reaction mixtures. From these results, only furans bearing the sulfoxide at C-3 of the ring are able to give stable products after photooxidation.[23]

In summary, we have successfully synthesized four new enantiomerically pure (*S*)-*p*-tolylsulfinyl substituted furans **1b–e** and shown that the MB sensitized photooxidation afforded (*S*)-3-(*p*-tolylsulfinyl)-1,4-dicarbonyl alkenes **2a**, **2d** and **2e** when the sulfoxide in the furan precursor was situated at C-3. We are now studying the reactivity of such chiral dicarbonyl compounds as dienophiles and Michael acceptors. The results will be reported in due course.

3. Experimental

Melting points were obtained in open capillary tubes and are uncorrected. ^1H and ^{13}C NMR spectra were recorded at 300 MHz and 75.5 MHz in $CDCl_3$. All reactions were monitored by TLC which was performed on precoated sheets of silica gel 60, and flash chromatography was carried out with silica gel 60 (230–400 mesh) of Merck. Eluting solvents are indicated in the text. The apparatus for inert atmosphere experiments was dried by flaming it in a stream of dry argon. THF and Et_2O were distilled over sodium and benzophenone ketyl radical anion. CH_2Cl_2 was

dried over P_2O_5 and stored over molecular sieves. Absolute methanol was purchased from Fluka. For routine workup, hydrolysis was carried out with saturated aqueous NH_4Cl, extractions with CH_2Cl_2 and ethyl acetate and solvent drying with $MgSO_4$. Optical rotations were measured with a 141 Perkin–Elmer polarimeter. Specific rotations are given in units of 10^{-1} deg cm^2 g^{-1}.

3.1. General procedure for the synthesis of p-tolylsulfinylfurans: method A

A solution of *n*-BuLi in hexane was added dropwise to a solution of the corresponding furan **3**–**6** in THF at −78°C. After 1 h stirring, $Br_2Mg{\cdot}Et_2O$ was slowly added, and the resulting mixture was warmed to −60°C and stirred for 2 h. A solution of (S*S*)-menthyl-*p*-toluenesulfinate in THF was then added. After conversion of all the starting furan, work-up afforded a crude mixture that was purified by flash chromatography.

3.2. (+)-(*S*S)-3-(p-*Tolylsulfinyl*)*furan* ***1a***

Compound **1a** (2.33 g, 11.3 mmol, 82% yield) was obtained following method A from 3-bromofuran **3** (13.9 mmol) in THF (20 ml) using $Br_2Mg{\cdot}Et_2O$ (41.6 mmol) and (−)-(S*S*)-menthyl-*p*-toluenesulfinate (13.9 mmol) in THF (10 ml). Eluent: hexane:Et_2O, 1:2, $R_f = 0.20$. White solid. $[\alpha]_D^{20}$ +63.3 (c 1.00, $CHCl_3$); $[\alpha]_D^{20}$ +43.5 (c 1.00, acetone). Lit.[8b] $[\alpha]_D^{20}$ +31. (c 2.50, acetone). NMR data are superimposable with those previously reported.

3.3. (+)-(*S*S)-4-Bromo-3-(p-*tolylsulfinyl*)*furan* ***1b***

Compound **1b** (464 mg, 1.6 mmol, 74% yield) was obtained following method A from 3,4-dibromofuran **4** (500 mg, 2.2 mmol) in THF (8 ml) using $Br_2Mg{\cdot}Et_2O$ (6.6 mmol) and (−)-(S*S*)-menthyl-*p*-toluenesulfinate (2.2 mmol) in THF (10 ml). Eluent: hexane:Et_2O, 3:1, $R_f = 0.18$. White solid. Mp: 47–48°C; $[\alpha]_D^{20}$ +53.0 (c 1.03, $CHCl_3$); ^{1}H NMR δ: 2.42 (3H, s, C**H**$_3$-Tol), 7.47 (1H, d, $J_{2,5}$ 1.7 Hz, **H**-C5), 7.63 (H, d, $J_{2,5}$ 1.7, **H**-C2), 7.32 and 7.64 (4H, system AA′BB′, **H**-arom); ^{13}C NMR δ: 21.4 (**C**H$_3$-Tol), 98.1 (**C**-4), 125.5 and 129.9 (**C**H-arom), 130.6 (**C**-3), 139.0 and 142.2 (**C**-arom), 143.3 and 145.0 (**C**-2 and **C**-5); MS [*m*/*z* (relative intensity)]: 286 (35), 284 (31), 268 (3), 236 (100), 139 (21), 91 (43), 65 (40). HRMS (EI) calcd for $C_{11}H_9O_2BrS$: 283.95099, found: 283.95032. Anal. calcd for $C_{11}H_9O_2BrS$: C, 46.34; H, 3.18. Found: C, 46.35; H, 3.17.

3.4. (+)-(*S*S)-5-Methyl-2-(p-*tolylsulfinyl*)*furan* ***1c***

Compound **1c** (317 mg, 1.4 mmol, 72%) was obtained following method A from 2-methylfuran **5** (114.0 μl, 2 mmol) in THF (5 ml) using $Br_2Mg{\cdot}Et_2O$ (6.6 mmol) and (−)-(S*S*)-menthyl-*p*-toluenesulfinate (588.0 mg, 2.0 mmol) in THF (5 ml). Eluent hexane:Et_2O, 1:3; $R_f = 0.35$. $[\alpha]_D^{20}$ +153.5 (c 0.96, $CHCl_3$); $[\alpha]_D^{20}$ +195 (c 1.00, acetone); Lit.[8c] $[\alpha]_D^{20}$ +165 (c 1.00, acetone); ^{1}H NMR δ: 2.29 (3H, s, C**H**$_3$-C5), 2.42 (3H, s, C**H**$_3$-Tol), 6.04 (1H, dd, $J_{3,4}$ 3.3, $J_{3,Me}$ 0.8, **H**-C4), 6.68 (1H, d, $J_{4,3}$ 3.3, **H**-C3), 7.32 and 7.58 (4H, system AA′BB′, **H**-arom); ^{13}C NMR δ: 13.8 (**C**H$_3$-C5), 21.4 (**C**H$_3$-Tol), 107.6 and 117.7 (**C**-3 and **C**-4), 124.9 and 129.7 (**C**H-arom), 138.3 and 141.4 (**C**-arom), 151.2 and 158.1 (**C**-2 and **C**-5); MS [*m*/*z* (relative intensity)]: 220 (1), 204 (3), 172 (100), 129 (42), 97 (31), 91 (16), 43 (26). HRMS (EI) calcd for $C_{12}H_{12}O_2S$: 220.05580, found: 220.05510. Anal. calcd for $C_{12}H_{12}O_2S$: C, 65.42; H, 5.49. Found: C, 65.32; H, 5.51.

3.5. (−)-(SS)-4-Bromo-2,5-dimethyl-3-(p-tolylsulfinyl)furan **1d**

Compound **1d** (370 mg, 1.2 mmol, 81%) was obtained following method A from 3,4-dibromo-2,5-dimethylfuran **6** (370 mg, 1.5 mmol) in THF (5 ml) using $Br_2Mg{\cdot}Et_2O$ (4.4 mmol) and (−)-(S*S*)-menthyl-*p*-toluenesulfinate (429.2 mg, 1.5 mmol) in THF (10 ml). Eluent: hexane:Et_2O, 3:1, $R_f = 0.32$. White solid. Mp: 92–93°C; $[\alpha]_D^{20}$ −57.3 (c 1.04, $CHCl_3$); ^{1}H NMR δ: 2.18 (3H, s, C**H**$_3$-C5), 2.39 (3H, s, C**H**$_3$-Tol), 2.46 (3H, s, C**H**$_3$-C2), 7.26 and 7.48 (4H, system AA′BB′, **H**-arom.); ^{13}C NMR δ: 11.5 and 12.7 (**C**H$_3$-furan), 21.3 (**C**H$_3$-Tol), 94.6 (**C**4), 121.9 (**C**3), 124.8 and 129.6 (**C**H-arom), 139.6 and 140.7 (**C**-arom), 149.4 and 154.9 (**C**-2 and **C**-5); MS [*m*/*z* (relative intensity)]: 314 (10), 312 (19), 266 (14), 295 (47), 173 (33), 139 (32), 91 (37), 43 (100). HRMS (EI) calcd for $C_{13}H_{13}O_2BrS$: 311.98196, found: 311.98294. Anal. calcd for $C_{13}H_{13}O_2BrS$: C, 49.85; H, 4.18. Found: C, 49.70; H, 4.18.

3.6. (−)-(SS)-2,5-Dimethyl-3-(p-tolylsulfinyl)furan **1e**

A solution of *n*-BuLi (1.76 mmol) in hexane was added dropwise to a solution of (−)-(S*S*)-4-bromo-2,5-dimethyl-3-(*p*-tolylsulfinyl)furan **1d** (500 mg, 1.6 mmol) in THF (12 ml) at −78°C. The mixture was stirred for 30 min at −78°C and then distilled water (6 ml) was added. The reaction mixture was warmed to rt and extracted with Et_2O and ethyl acetate. The combined organic layers were washed with brine, dried over $MgSO_4$, and the solvents were removed under reduced pressure. The resulting crude reaction was purified by flash chromatography (hexane:Et_2O, 1:3, $R_f = 0.38$) affording **1e** as a yellow oil in 30% yield. $[\alpha]_D^{20}$ −76.6 (c 0.50, $CHCl_3$); ^{1}H NMR δ: 2.17 (3H, s, C**H**$_3$-C5), 2.40 (3H, s, C**H**$_3$-*p*Tol), 2.52 (3H, s, C**H**$_3$-C2), 5.78 (1H, s, **H**-C4), 7.28 and 7.49 (4H, system AA′BB′, **H**-arom); ^{13}C NMR δ: 12.3 and 13.4 (**C**H$_3$-furan), 21.3 (**C**H$_3$-Tol), 102.8 (**C**-4), 124.2 (**C**H-arom), 125.1 (**C**-3), 129.7 (**C**H-arom), 140.7 and 142.2 (**C**-arom), 152.2 and 154.0 (**C**-2 and **C**-5); MS [*m*/*z* (relative intensity)]: 234 (16), 217 (60), 186 (35), 143 (31), 91 (26), 43 (100). (*RS*)-*n*-Butyl-*p*-tolyl sulfoxide[24] was also obtained in a 23% yield as a white solid. ^{1}H NMR δ: 0.86 (3H, t, J_{vic} 7.2, C**H**$_3$-CH$_2$), 1.33–1.43 (2H, m, CH$_3$-C**H**$_2$-), 1.52–1.58 (2H, m, -C**H**$_2$-), 2.36 (3H, s, C**H**$_3$-Tol), 2.70–2.75 (2H, d, -C**H**$_2$S(O)Tol), 7.26 and 7.47 (4H, system AA′BB′, **H**-arom). HRMS (EI) calcd for $C_{13}H_{14}O_2S$: 234.07145, found: 234.07204.

3.7. (SS,SS)-2-(1,1′-Bis-p-tolylsulfinyl)methyl-5-methylfuran **1f**

To a solution of LDA (2.2 mmol) in THF (10 ml), at −78°C, 2,5-dimethylfuran **7** (212 μl, 2.0 mmol) in THF (5 ml) was added. The mixture was warmed to rt, stirred for 5 h and then cooled at −78°C. A solution of (−)-(S*S*)-menthyl-*p*-toluenesulfinate (294 mg, 1.0 mmol) in THF (5 ml) was added. The resulting mixture was stirred at −78°C for an additional hour and left to warm to rt. Work-up led to a crude that was purified by column chromatography (hexane:Et_2O, 2:1) to yield pure **1f** (101 mg, 0.3 mmol, 54%) as a white solid. Eluent: hexane:Et_2O, 1:3, $R_f = 0.28$. Mp: 90–91°C; $[\alpha]_D^{20}$ +134.4 (c 0.96, $CHCl_3$); ^{1}H NMR δ: 1.95, (3H, s, C**H**$_3$-C5), 2.34 and 2.35 (two s, 3H each other, C**H**$_3$-Tol), 4.64 (1H, s, C**H**-(SOTol)$_2$), 5.94 (1H, d, J_{vic} 3.2, **H**-C4), 6.58 (1H, d, J_{vic} 3.2, **H**-C5), 7.15, 7.18, 7.23 and 7.31 (8H, two systems AA′BB′, **H**-arom); ^{13}C NMR δ: 13.2 (**C**H$_3$-C5), 21.3 (**C**H$_3$-Tol), 89.7 (-**C**H-(SOTol)$_2$, 107.4 and 117.7 (**C**-3 and **C**-4), 117.7 124.9, 129.5 and 129.7 (**C**H-arom), 136.0, 136,9, 138.6 and 141.9 (**C**-arom), 142.2 and 154.3 (**C**-2 and **C**-5). Anal. calcd for $C_{20}H_{20}O_3S_2$: C, 64.48; H, 5.41. Found: C, 64.55; H, 5.39.

3.8. General procedure for the photosensitized oxidation of p-tolylsulfinylfurans: method B

A solution of the corresponding *p*-tolylsulfinylfuran in a dry solvent (CH_3OH or CH_2Cl_2) was irradiated with a halogen lamp (Tungsram, 500 W) in the presence of MB. During the irradiation, dry oxygen was bubbled through the solution which was cooled at −40°C. Progress of the reaction was checked by TLC (hexane:Et_2O, 1:3). When the reaction was completed (20 min) the solution was degassed at 0°C by bubbling Ar through (15 min), and then Me_2S was added. The reaction mixture was left to reach rt, and stirred for 3 h. As soon as the reduction was completed, the solvent was removed under reduced pressure, Cl_4C (30 ml) was added and the mixture was filtered to remove MB. Evaporation of the solvents gave a clean mixture of compounds **2** and dimethyl sulfoxide.

3.9. (+)-(2E,*S*S)-2-(p-*Tolylsulfinyl*)-2-buten-1,4-dial **2a**

Compound **2a** (222 mg, 0.8 mmol, 84%) was obtained following method B from **1a** (200 mg, 1.0 mmol) in CH_2Cl_2 (20 ml), MB (7×10^{-3} mmol) and Me_2S (155 μml, 1.9 mmol). The yield was determined from the crude reaction consisting of a mixture of (*E*)-**2a** and dimethyl sulfoxide in a 58:42 ratio by ^{1}H NMR. All attempts to purify **2a** by chromatographic methods failed since it decomposes on contact with the silica gel. Eluent: hexane:Et_2O, 1:3, $R_f=0.40$. $[\alpha]_D^{20}$ +225.0 (c 0.67, $CHCl_3$); ^{1}H NMR 2.39 (3H, s, C**H**$_3$-Tol), 7.29 (2H, system AA′BB′, **H**-arom), 7.47 (1H, d, $J_{3,4}$ 4.3, **H**-C3), 7.65 (2H, system AA′BB′, **H**-arom), 10.25 (1H, s, **H**-Cl), 10.32 (1H, d, $J_{4,3}$ 4.3 Hz, **H**-C4). IR (KBr, liquid film): 1759, 1648; MS [*m*/*z* (relative intensity)]: 193 ([M^+−29], 6), 139 (100), 123 (86), 91 (85), 82 (12).

3.10. (−)-(3Z,*S*S)-4-Bromo-3-(p-*tolylsufinyl*)-3-hexen-2,5-dione **2d**

Compound **2d** (240 mg, 0.9 mmol, 94%) was obtained following method B from **1d** (290 mg, 0.9 mmol) in CH_3OH (20 ml), MB (7×10^{-3} mmol) and Me_2S (135 μl, 1.8 mmol). The yield was determined from the crude reaction consisting of a mixture of **2d** and DMSO in a 67:33 ratio by ^{1}H NMR. All attempts to purify **2d** by chromatographic methods failed since it decomposes on contact with the silica gel. Eluent: hexane:Et_2O, 1:3. $[\alpha]_D^{20}$ −396.1 (c 2.80, $CHCl_3$); ^{1}H NMR δ: 2.31 (3H, s, **H**-C6), 2.42 (3H, s, C**H**$_3$-Tol), 2.51 (3H, s, **H**-C1), 7.34 and 7.69 (4H, system AA′BB′, **H**-arom); ^{13}C NMR δ: 21.6 (**C**H$_3$-Tol), 28.2 and 32.5 (**C**-1 and **C**-6), 99.4 (**C**-4), 123.5 (**C**-3), 125.2 and 130.3 (**C**H-arom), 137.9 and 143.2 (**C**-arom.), 193.2 and 195.6 (**C**-2 and **C**-5); IR (KBr, liquid film): 1710, 1620; MS [*m*/*z* (relative intensity)]: 314 ([M^+−15], 8), 312 (9), 269 (13), 191 (13), 161 (18), 139 (100), 123 (15), 91 (33), 43 (63).

3.11. (−)-(3E,*S*S)-3-(p-*Tolylsulfinyl*)-3-hexen-2,5-dione **2e**

Compound **2e** (57 mg, 0.2 mmol, 86%) was obtained following method B from **1e** (50 mg, 0.2 mmol) in CH_3OH (20ml), MB (1.6×10^{-3} mmol) and Me_2S (30 μl, 0.4 mmol). The yield was determined from the crude reaction consisting of a mixture of **2c** and DMSO in a 50:50 ratio by ^{1}H NMR. All attempts to purify **2c** by chromatographic methods failed since it decomposes on contact with the silica gel. Eluent: hexane:Et_2O, 1:3. $[\alpha]_D^{20}$ −377.3 (c 2.00, $CHCl_3$); ^{1}H NMR δ 2.36 (3H, s, **H**-C6), 2.39 (3H, s, C**H**$_3$-Tol), 2.41 (3H, s, **H**-Cl), 6.93 (1H, s, **H**-C4), 7.32 and 7.50 (4H, system AA′BB′, **H**-arom); ^{13}C-NMR δ: 21.9 (**C**H$_3$-Tol), 30.3 and 31.0 (**C**-1 and **C**-6), 125.0, 125.9

and 130.5 (**C**-4 and **C**H-arom), 129.9 (**C**-3), 136.9 and 143.4 (**C**-arom), 195.4 and 198.6 (**C**-2 and **C**-5); IR (KBr, liquid film): 1715, 1625; MS [*m*/*z* (relative intensity)]: 234 ([M^+-16], 15), 139 (100), 123 (87), 91 (85), 43 (48).

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