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NBS/DMSO-mediated synthesis of (2,3-dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanols from aryloxymethylthiiranes

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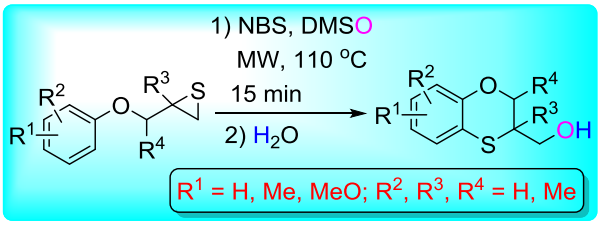

Abstract: (2,3-Dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanols were synthesized via reactions of aryloxymethylthiiranes and *N*-bromosuccinimide (NBS) in DMSO under microwave irradiation. The reaction mechanism was proposed as an intramolecular aromatic electrophilic substitution of 1-bromo-2-(aryloxymethyl)thiiran-1-iums, generated from aryloxymethylthiiranes and NBS, and subsequent DMSO nucleophilic ring opening reaction of thiiran-1-iums, followed by the water displacement. The current method provides a direct and simple strategy in efficient preparation of (2,3-dihydrobeno[*b*][1,4]oxathiin-3-yl)methanols from readily available aryloxymethylthiiranes.

Introduction

2,3-Dihydrobenzo[*b*][1,4]oxathiine derivatives have received great attention in chemical, medicinal, and pharmaceutical research. During the last decades their syntheses as well as applications as antioxidants, hypertensive agents, estrogen receptor modulators, adrenoreceptor antagonists, artificial sweetener, and anticancer agents (Figure 1) have been reported in dozens of papers and patents.[1] Many synthetic methods have been developed for the preparation of 2,3-dihydrobenzo[*b*][1,4]oxathiines, especially 2-monosubstituted and 2,3-disubstituted 2,3-dihyrobenzo[*b*][1,4]oxathiines.[2] However, only limited methods can be used to achieve the synthesis of 3-substituted 2,3-dihydrobenzo[*b*][1,4]oxathiines.

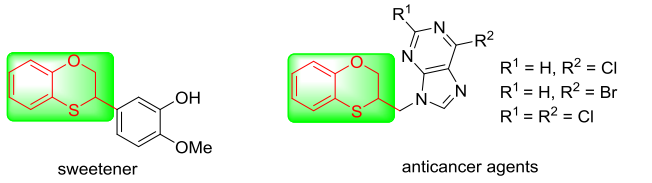

Figure 1. Sweetener and anticancer agents derived from 3-substituted 2,3-dihydrobenzo[*b*][1,4]oxathiines

Although 3-monosubstituted or 3,3-disubstituted 2,3-dihydrobenzo[*b*][1,4]oxathiines have been widely applied in organic synthesis and medicinal chemistry, their synthetic methods are very limited to date. Several synthetic methods for benzo[*b*][1,4]oxathiines have been developed. a) 3-Substituted 2,3-dihydrobenzo[*b*][1,4]oxathiine derivative, anticancer agent 6-chloro-3-(2,3-dihydrobenzo[*b*][1,4]oxathiin-3-ylmethyl)purine, was obtained by applying a standard Mitsunobu protocol that led to a six-membered ring contraction from 3,4-dihydro-2*H*-benzo[*b*][1,5]oxathiepin-3-ol via an episulfonium intermediate.[3] b) 3-Chloromethyl-3-methyl-2,3-dihydrobenzo[*b*][1,4]oxathiines were prepared by the reaction of several 2-methylallyl phenyl ethers with sulfur dichloride.[4] c) 8-Chloro-7-methoxy-3-methyl-2,3-dihydrobenzo[*b*][1,4]oxathiine was constructed from 2-[(2,3-dichloro-4-methoxyphenyl)thio]propanol in the presence of sodium hydride *via* an intramolecular aromatic nucleophilic substitution.[5] d) 3-Aryl-2,3-dihydrobenzo[*b*][1,4]oxathiine was synthesized by the *N*-bromosuccinimide (NBS)-promoted oxidative rearrangement of 1,3-

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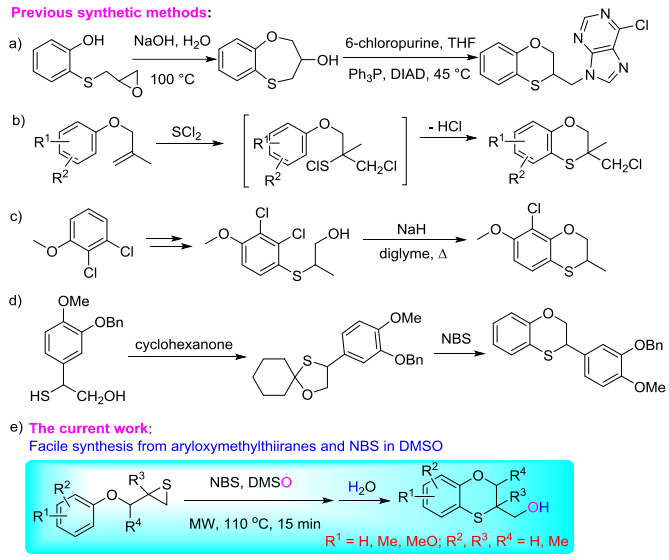
oxathiospiro[4.5]decane derived from 2-aryl-2-mercaptoethanol and cyclohexanone (Scheme 1).[6] In view of the importance of 2,3-dihydrobenzo[*b*][1,4]oxathiines and drawbacks of the reported synthetic methods, the efficient synthesis of these compounds is still in high demand. Thiiranes have unique chemical properties and have been of interest in our laboratory in recent years.[7,8] They are readily available from the corresponding oxiranes. Thus, we envisioned that 2,3-dihydrobenzo[*b*][1,4]oxathiines should be synthesized from the ring expansion of aryloxymethylthiiranes. We, herein, present a new synthetic strategy for the preparation of (2,3-dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanols through the *N*-bromosuccinimide-promoted ring expansion reactions of aryloxymethylthiiranes in dimethyl sulfoxide (DMSO) under microwave conditions (Scheme 1).

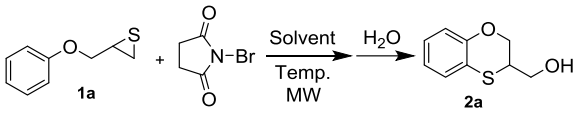


Scheme 1. Synthesis of 3-monosubstituted and 3,3-disubstituted 2,3-dihydrobenzo[*b*][1,4]oxathiines.

Results and discussion

At the outset of this study, 2-(phenoxymethyl)thiirane (**1a**) and NBS (*N*-bromosuccinimide) were employed as the model reactants to optimize reaction conditions (Table 1). Initially, we screened solvents and found that DMF, toluene, DCE (1,2-dichloroethane), and MeCN were unsuitable solvents to get the corresponding product **2a** (Table 1, entries 1–4). When DMSO was used as solvent, product **2a** was obtained in 42% yield (Table 1, entry 5). We further optimized the reactant ratio of **1a**:NBS and found that the yield dropped sharply when **1a**:NBS in 2:1 (Table 1, entry 6). When the ratio of **1a**:NBS was decreased to 1:2, the reaction system became very complex because various brominated phenols generated (*vide post*) (Table 1, entry 7). The reactions with ratios of **1a**:NBS in 1:1.2 and 1:1.5 gave the product in 5% and 7% yields, respectively (Table 1, entries 8 and 9). It was noteworthy that no desired product was generated when NCS (*N*-chlorosuccinimide) and NIS (*N*-iodosuccinimide) were used as halogeniums (X^+) instead of NBS (Table 1, entries 10 and 11). The other choices of brominium (Br^+), which generated from $KBr/K_2S_2O_8$, DBDMH (1,3-dibromo-5,5-dimethyl hydantoin), were also attempted and only trace amount of product **2a** was obtained when DBDMH was used (Table 1, entries 12 and 13). When the reaction time was increased from 15 mins to 20 mins, the yield was slightly decreased (Table 1, entry 14 *vs* entry 5). The yield further decreased when oil-bath heating for 120 mins instead of microwave irradiation for 20 mins (Table 1, entry 15). The yield also decreased when the reaction was conducted at 80 °C under microwave irradiation (Table 1, entry 16). Considering the generation of HBr in the reaction mixture (*vide post*), TEA and pyridine were added, respectively, as bases into the reaction mixture. But no obvious impact on the yield was observed (Table 1, entries 17 and 18). The optimum reaction conditions were finally identified as follows: **1a**:NBS = 1:1 in DMSO as solvent at 110 °C for 15 mins microwave irradiation (Table 1, entry 5).

Table 1. Optimization for the reaction of 2-(phenoxymethyl)thiirane (**1a**) and NBS[a]



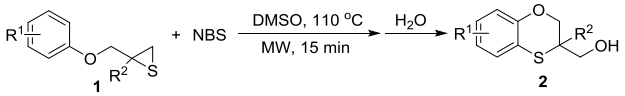
Entry	**1a**:NBS	Solvent	Temp (°C)	Time (min)	Yield[b] (%)
1	1:1	DMF	110	15	0
2	1:1	Toluene	110	15	0
3	1:1	DCE	110	15	0
4	1:1	MeCN	110	15	0
5	1:1	DMSO	110	15	42
6	2:1	DMSO	110	15	3
7	1:2	DMSO	110	15	mess
8	1:1.2	DMSO	110	15	5
9	1:1.5	DMSO	110	15	7
10	1:1[c]	DMSO	110	15	0
11	1:1[d]	DMSO	110	15	0
12	1:1[e]	DMSO	110	15	0
13	1:1[f]	DMSO	110	15	trace
14	1:1	DMSO	110	20	25
15[g]	1:1	DMSO	110	120	17
16	1:1	DMSO	80	15	15
17[h]	1:1	DMSO	110	15	23
18[i]	1:1	DMF	110	15	24

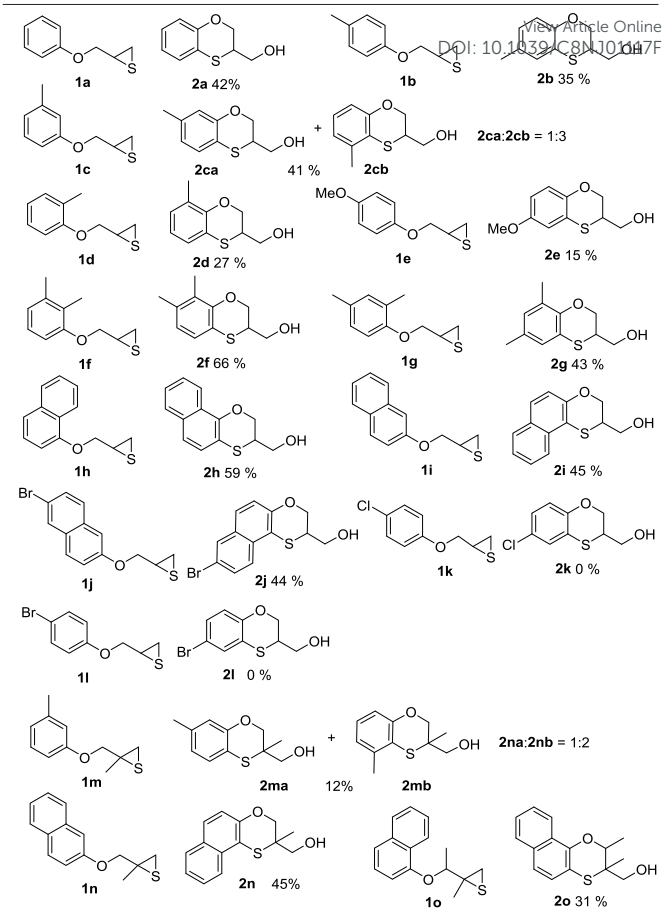
a) All reactions were conducted on a 0.25 mmol scale of **1a** and NBS in 5 mL of solvent in a 10 mL microwave tube and were stirred at 110 °C under microwave

irradiation in a sealed vessel. b) Yield of isolated product. c) NCS instead of NBS. d) NIS instead of NBS. e) $KBr/K_2S_2O_8$ instead of NBS. f) DBDMH (1,3-dibromo-5,5-dimethyl hydantoin) instead of NBS. g) Oil-bath heating instead of microwave irradiation. h) TEA (28 mg, 0.28 mmol) was added as a base. i) Pyridine (22 mg, 0.28 mmol) was added as a base.

With the optimized reaction conditions, the reaction scope was then evaluated (Table 2). Various aryloxymethylthiiranes **1** were subjected to the reaction conditions with NBS in DMSO under microwave irradiation. The results are presented in Table 2. Phenoxymethylthiirane (**1a**) and *meta*-methylphenoxymethylthiirane (**1c**) produced the corresponding products **2a**, **2ca** and **2cb** in relatively higher yields because the reactive positions locate on the *ortho* and *para*-positions of the activating methyl group for substrate **1c**. Two regioisomeric products **2ca** and **2cb** were obtained from *meta*-methylphenoxymethylthiirane (**1c**) due to the existence of two different activated (*ortho* and *para*-)positions. However, *para*/*ortho*-methylphenoxymethylthiiranes (**1b** and **1d**) and *para*-methoxyphenoxymethylthiirane (**1e**) gave rise to the corresponding products **2b**, **2d**, and **2e** in relatively lower yields because their reaction positions are the *meta*-position of the methyl and methoxy groups (Table 2). *meta*-Methyl and methoxy groups are deactivating groups in the aromatic electrophilic substitution according to Hammett constants. In comparison with monomethyl substituted phenoxymethylthiiranes **1b-d**, more electron-rich dimethyl substituted phenoxymethylthiiranes **1f-g** gave rise to the corresponding products **2f-g** in relatively higher yields. We further extended thiiranes **1** from phenoxymethylthiiranes to naphthyloxymethylthiiranes, (naphthalen-1-yloxymethyl)thiirane (**1h**), (naphthalen-2-yloxymethyl)thiirane (**1i**), and (6-bromonaphthalen-2-yloxymethyl)thiirane (**1j**) generated the corresponding products **2h-j** in moderate yields. However, no desired products were observed for electron-deficient 2-(4-chlorophenoxymethyl)thiirane (**1k**) and 2-(4-bromophenoxymethyl)thiirane (**1l**) (Table 2). Geminal disubstituted 2-methyl-2-(3-methylphenoxymethyl)thiirane (**1m**) reacted with NBS in DMSO to afford two isomeric corresponding products **2ma** and **2mb** in low yields. Geminal disubstituted 2-methyl-2-(naphthalen-2-yloxymethyl)thiirane (**1n**) gave product **2n** in a satisfactory yield. Similarly, geminal disubstituted 2,3-dimethyl-2-(naphthalen-1-yloxymethyl)thiirane (**1o**) gave the corresponding product **2o** as expected.

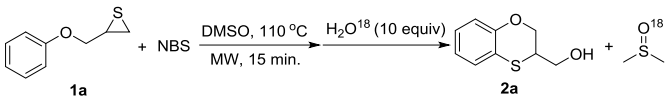
Table 2. Scope of substrates[a]





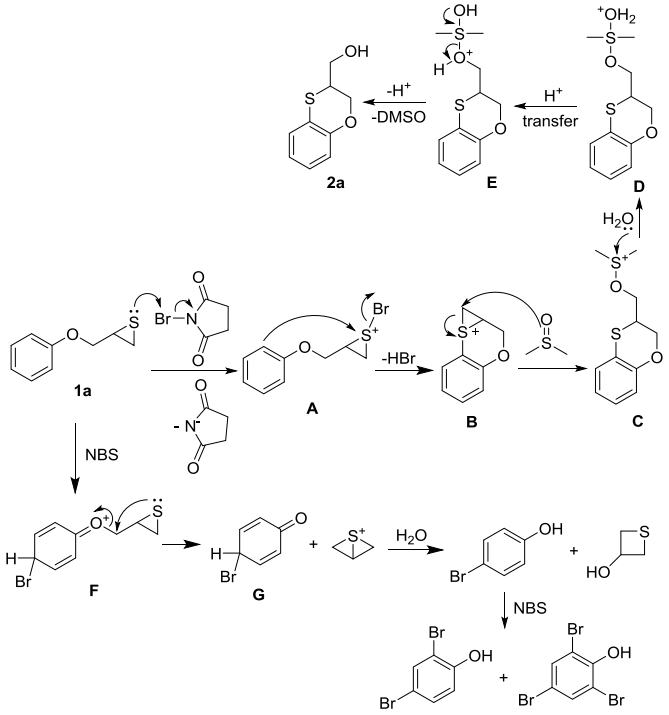
[a]Reaction conditions: Thiirane **1** (0.25 mmol) and NBS (0.25 mmol) were added in DMSO (5 mL) in a 10 mL microwave tube, then the reaction mixture was stirred at 110 °C for 15 mins under microwave irradiation in a sealed vessel. After cooling water (30 mL) was added, the mixture was extracted with DCM (20 mL X 3), and the combined extracts were washed with brine, dried over anhydrous sodium sulfate, and concentrated *in vacuo*, the resulting residue was purified by silica gel column chromatography (200-300 mesh, hexanes-EtOAc, 10:1, *v/v*) to afford the product **2**. All yields are isolated yields.

To illustrate the reaction mechanism, we performed the model reaction under the optimized conditions with treatment with H_2O^{18} (Scheme 2). After the reaction was complete, no O^{18}-**2a** was obtained on the basis of mass spectral analysis of product **2a**. However, the GC-MS analysis of the reaction mixture indicated that the relative intensity of O^{18}-DMSO at *m/z* 80 (compared with that of DMSO at *m/z* 78, the base peak) increased slightly from original 4.7% (before the reaction) to the current 7.6% (after the reaction). The results reveal that water does not nucleophilically attacks the thiiran-1-nium in intermediate **B**, generated from the aromatic electrophilic substitution of the aryl group and 1-bromothiiran-1-ium ion **A**. Instead, it should be that dimethylsulfoxide undergoes an ring opening reaction of the thiiran-1-nium in intermediate **B** from its less substituted ring carbon atom, leading to intermediate **C**. Water attacks the sulfurium in intermediate **C** during treatment with water to afford the desired product **2a** (Scheme 3).



Scheme 2. Designed experiment for investigating the water-participated reaction step with H_2O^{18}.

Considering the reaction mechanism, the reaction of thiirane **1a** was selected as an example to illustrate the mechanism (Scheme 3). First, thiirane **1a** as a nucleophile attacks NBS to generate an intermediate 1-bromothiiran-1-ium ion **A**, which further undergoes an intramolecular aromatic electrophilic substitution to afford intermediate **B**. DMSO undergoes a ring opening reaction of the thiiran-1-nium in intermediate **B** from its less substituted ring carbon atom, affording intermediate **C**. During workup, water attacks the sulfurium in intermediate **C**, yielding intermediate **D**. After proton transfer and loss of protonated DMSO, the desired product **2a** is generated (Scheme 3).



Scheme 3. Proposed mechanisms for the synthesis of (2,3-dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanol and the competitive side reactions.

Although the reaction conditions were carefully optimized, low to good yields were obtained. The low yields are attributed to the competitive side reaction, the bromination of the phenyl group. In the presence of NBS, electron-rich phenoxy group can be brominated on its *para*- or/and *ortho*-position(s). Herein, only *para*-brominated product is shown, generating intermediate **F**, which further undergoes an intramolecular nucleophilic displacement to give rise to 4-bromo-2,5-cyclohexadienone (**G**) and 1-thiabicyclo[1.1.0]butanium. **G** can further tautomerize into more stable aromatic *para*-bromophenol, which can be further brominated. 1-Thiabicyclo[1.1.0]butanium converts into thietan-3-ol when treatment with water. Bromophenols were observed in most reactions in GC-MS analysis.

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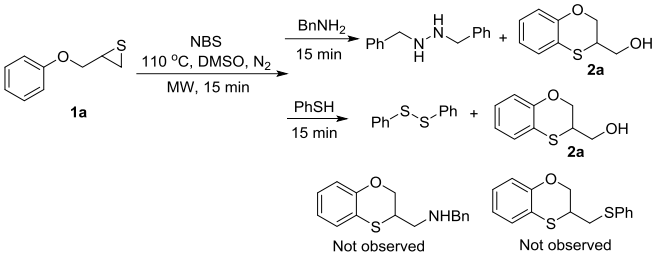
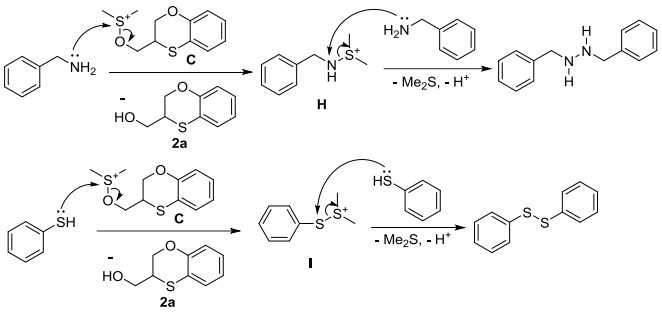
To verify water attacking process, we designed and conducted two reactions with benzylamine and thiophenol as nucleophiles in the reaction of thiirane **1a** and NBS. Both benzylamine and thiophenol are stronger nucleophiles than water. As expected, the corresponding amine and sulfide derivatives were not observed. Instead, (2,3-dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanol (**2a**), *N*,*N*'-dibenzylhydrazine, and 1,2-diphenyldisulfane were detected in the reaction mixtures, respectively, by GC-MS analysis (Scheme 4). Both results support our proposed reaction mechanism.



Scheme 4. Designed reactions for investigation on the proposed mechanism.



Scheme 5. Formation mechanisms of *N,N*'-dibenzylhydrazine and 1,2-diphenyldisulfane.

The formation mechanisms of *N,N*'-dibenzylhydrazine and 1,2-diphenyldisulfane were also proposed. Both benzylamine and thiophenol as nucleophiles attack the sulfurium in intermediate **C** to generate intermediates **H** and **I**, respectively, after release of product **2a**. Both benzylamine and thiophenol further nucleophilically attack the nitrogen atom in

intermediate **H** and the sulfur atom in intermediate **I**, respectively, to afford *N,N*'-dibenzylhydrazine and 1,2-diphenyldisulfane by loss of dimethyl sulfide and proton (Scheme 5).

Conclusions

In summary, we developed a direct and simple strategy for the preparation of (2,3-dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanols, important intermediates in medicinal chemistry. The method mainly utilized the reaction of aryloxymethylthiiranes and NBS in DMSO under microwave irradiation, affording 3-monosubstituted, 2,3- and 3,3-disubstituted 2,3-dihydrobenzo[*b*][1,4]oxathiines in acceptable to good yields. The method also had advantages of cheap and easy access to raw materials, short reaction times, and simple operation. The reaction mechanism was proposed.

Experimental

Unless otherwise noted, all materials were purchased from commercial suppliers. Flash column chromatography was performed using silica gel (normal phase, 200-300 mesh) from Branch of Qingdao Haiyang Chemical Industry. Petroleum ether (PE) used for column chromatography is 60–90 °C fraction, and the removal of residue solvent was accomplished under rotovap. Reactions were monitored by thin-layer chromatography on silica gel GF254 coated 0.2 mm plates from Institute of Yantai Chemical Industry. The plates were visualized under UV light, as well as other TLC stains (10% phosphomolybdic acid in ethanol; 1% potassium permanganate in water; 10 g of iodine absorbed on 30 g of silica gel). ^{1}H and ^{13}C NMR spectra were recorded on a Bruker 400 MHz spectrometer in $CDCl_3$ with TMS as an internal standard, and the chemical shifts (δ) are reported in parts per million (ppm). All coupling constants (*J*) in ^{1}H NMR spectra are absolute values given in hertz (Hz) with peaks labeled as singlet (s), broad singlet (brs), doublet (d), triplet (t), quartet (q), and multiplet (m). The IR spectra (KBr pellets, *v* [cm^{-1}]) were taken on a Nicolet 5700 FTIR spectrometer. HRMS measurements were carried out on an Agilent LC/MSD TOF mass spectrometer. LRMS measurements were carried out on Thermo Trace 1300/ISQ QD system. Melting points were obtained on a Yanaco MP-500 melting point apparatus and are uncorrected. All the microwave reactions were conducted in CEM Discover SP microwave system equipped with an infrared temperature detector.

General procedure for synthesis of oxiranes 4a-c, 4h, and 4l, 4m-o

General procedure for the preparation of oxiranes 3

To a stirred solution of phenol (25.0 mmol) in ethanol (30 mL) was added NaOH (30.0 mmol, 1.20 g). After stirring for 20 min at room temperature, 2-(chloromethyl)oxirane (75.0 mmol, 6.94 g) or 2-(chloromethyl)-2-methyloxirane (75.0 mmol, 7.99 g) was added dropwise over 30 min. The resulting mixture was stirred at room temperature for 24 h (TLC-monitoring). When the reaction was complete, the solvent was removed under reduced pressure. The residue was extracted with EtOAc (3 × 30 mL). The combined organic layers were washed with brine (20 mL), dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The obtained crude product was purified by column chromatography (silica gel, petroleum ether–ethyl acetate (PE–EtOAc), 100:1, v/v) to give pure oxirane **3**. The analytical data of known oxiranes **3** are identical to those reported previously.

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2-((2,4-Dimethylphenoxy)methyl)oxirane (3g)

Colorless oil, 2.91 g, yield 33%, R_f = 0.30 (Hexanes/EtOAc = 20:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 6.97 (s, 1H), 6.94 (d, *J* = 8.2 Hz, 1H), 6.72 (d, *J* = 8.2 Hz, 1H), 4.20 (dd, *J* = 11.2, 2.8 Hz, 1H), 3.96 (dd, *J* = 11.2, 5.5 Hz, 1H), 3.36 (dddd, *J* = 5.6, 4.0, 2.9, 2.9 Hz, 1H), 2.90 (dd, *J* = 5.0, 4.1 Hz, 1H), 2.78 (dd, *J* = 5.0, 2.7 Hz, 1H), 2.27 (s, 3H), 2.23 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): *δ* 154.5, 131.6, 130.5, 126.9, 126.8, 111.4, 68.9, 50.4, 44.7, 20.4, 16.1. IR (KBr): 2923, 1505, 1457, 862, 803 cm^{-1}. HR-MS (ESI) *m/z* [M + H]$^+$ calcd for $C_{11}H_{15}O_2^+$: 179.1067, found:179.1070..

2-Methyl-2-((naphthalen-2-yloxy)methyl)oxirane (3n)

White solid, m.p. 80 – 80 oC. 2.91 g, yield 49%, R_f = 0.58 (Hexanes/EtOAc = 10:1, v/v). ^{1}H NMR (400 MHz, CDCl3): δ 7.78 – 7.72 (m, 3H), 7.46 – 7.42 (m, 1H), 7.37 – 7.33 (m, 1H), 7.19 (dd, J = 8.9, 2.5 Hz, 2H), 7.14 (d, J = 2.3 Hz, 2H), 4.16 (d, J = 10.4 Hz, 2H), 4.07 (d, J = 10.4 Hz, 2H), 2.94 (d, J = 4.7 Hz, 1H), 2.78 (d, J = 4.7 Hz, 1H), 1.54 (s, 3H). ^{13}C NMR (101 MHz, CDCl3): δ 156.5, 134.4, 129.4, 129.1, 127.6, 126.8, 126.4, 123.8, 118.8, 106.9, 71.5, 55.5, 52.1, 18.6. IR (KBr): 2923, 1599, 1508, 1385 cm-1. HR-MS (ESI) *m/z* [M + H]$^+$ calcd for $C_{14}H_{15}O_2^+$: 215.1067, found: 215.1071.

General procedure for the preparation of thiiranes 1a–1g, 1m[8d]

A solution of oxirane **3** (24.0 mmol) and KSCN (9.31 g, 96.0 mmol) in water (30.0 mL) was heated to 40 °C and stirred for 24 h at the same temperature. The resulting mixture was diluted with EtOAc and washed with brine. The organic phase was dried (Na_2SO_4) and concentrated in vacuo. The residue was purified by column chromatography (silica gel, hexanes) to give thiirane **1**.

Phenoxymethylthiirane (1a)

Colorless oil, 2.91 g, yield 88%, R_f = 0.62 (Hexanes/EtOAc = 10:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 7.29 (t, *J* = 7.9 Hz, 2H), 6.97 (t, *J* = 7.6 Hz, 1H), 6.91 (d, *J* = 8.4 Hz, 2H), 4.22 (dd, *J* = 10.2, 5.4 Hz, 1H), 3.90 (dd, *J* = 10.2, 7.2 Hz, 1H), 3.30 – 3.24 (m, 1H), 2.61 (d, *J* = 6.0 Hz, 1H), 2.33 (d, *J* = 5.2 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$): *δ* 158.4, 129.5, 121.2, 114.7, 72.5, 31.4, 24.0. GC-MS (EI) *m/z* = 166 (M)$^+$ for $C_9H_{10}OS$.

(4-Methylphenoxy)methylthiirane (1b)

Colorless oil, 2.00 g, yield 56%, R_f = 0.91 (Hexanes/EtOAc = 5:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 7.07 (d, *J* = 8.4 Hz, 2H), 6.80 (d, *J* = 8.4 Hz, 2H), 4.18 (dd, *J* = 10.2, 5.6 Hz, 1H), 3.85 (dd, *J* = 10.2, 7.2 Hz, 1H), 3.27 – 3.21 (m, 1H), 2.58 (d, *J* = 6.4 Hz, 1H), 2.31 – 2.29 (m, 1H), 2.28

(s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 156.3, 130.5, 129.9, 114.6, 72.8, 31.4, 24.0, 20.4. GC-MS (EI) *m/z* = 180 $(M)^+$ for $C_{10}H_{12}OS$.

(3-Methylphenoxy)methylthiirane (1c)

Colorless oil, 1.79 g, yield 50%, R_f = 0.62 (Hexanes/EtOAc = 10:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.08 (t, *J* = 7.6 Hz, 1H), 6.70 (d, *J* = 7.6 Hz, 1H), 6.65 – 6.61 (m, 2H), 4.11 (dd, *J* = 10.4, 5.6 Hz, 1H), 3.79 (dd, *J* = 10.4, 7.2 Hz, 1H), 3.20 – 3.14 (m, 1H), 2.51 (d, *J* = 6.4 Hz, 1H), 2.24 (s, 3H), 2.23 (d, *J* = 5.6 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 158.4, 139.5, 129.2, 122.0, 115.5, 111.5, 72.4, 31.4, 23.9, 21.5. GC-MS (EI) *m/z* = 180 $(M)^+$ for $C_{10}H_{12}OS$.

2-((2-Methylphenyloxy)methyl)thiirane (1d)

Colorless oil, 2.05 g, yield 58%, R_f = 0.46 (Hexanes/EtOAc = 20:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.15 (t, *J* = 7.4 Hz, 2H), 6.89 (dt, *J* = 0.8, 7.4 Hz, 1H), 6.80 (d, *J* = 7.9 Hz, 1H), 4.22 (ddd, *J* = 10.3, 5.5, 0.8 Hz, 1H), 3.94 (dd, *J* = 10.4, 6.9 Hz, 1H), 3.33 – 3.27 (m, 1H), 2.61 (ddd, *J* = 6.2, 1.1, 1.1 Hz, 1H), 2.34 (dd, *J* = 5.3, 1.4 Hz, 1H), 2.27 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 156.6, 130.8, 127.1, 126.8, 121.0, 111.6, 72.7, 31.6, 23.9, 16.2. GC-MS (EI) *m/z* = 180 $(M)^+$ for $C_{10}H_{12}OS$.

2-((4-Methoxyphenoxy)methyl)thiirane (1e)

White solid, 65 – 66 °C, 2.35 g, yield 60%, R_f = 0.75 (Hexanes/EtOAc = 3:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.89 – 6.82 (m, 4H), 4.16 (dd, *J* = 10.4, 5.6 Hz, 1H), 3.86 (dd, *J* = 10.0, 6.8 Hz, 1H), 3.77 (s, 3H), 3.28 – 3.22 (m, 1H), 2.59 (d, *J* = 6.0 Hz, 1H), 2.30 (dd, *J* = 5.2, 1.2 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 154.2, 152.5, 115.8, 114.6, 73.4, 55.6, 31.5, 23.9. GC-MS (EI) *m/z* = 196 $(M)^+$ for $C_{10}H_{12}O_2S$.

2-((2,3-Dimethylphenoxy)methyl)thiirane (1f)

Colorless oil, 500 mg, yield 52%, R_f = 0.49 (Hexanes/EtOAc = 3:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.04 (t, *J* = 7.9 Hz, 1H), 6.81 (d, *J* = 7.5 Hz, 1H), 6.69 (d, *J* = 8.2 Hz, 1H), 4.20 (dd, *J* = 10.3, 5.5 Hz, 1H), 3.92 (dd, *J* = 10.3, 6.9 Hz, 1H), 3.33 – 3.27 (m, 1H), 2.61 (d, *J* = 6.2 Hz, 1H), 2.33 (dd, *J* = 5.3, 1.4 Hz, 1H), 2.28 (s, 3H), 2.19 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 156.4, 138.2, 125.8, 125.6, 122.9, 109.7, 73.1, 31.7, 23.9, 20.1, 11.7. IR (KBr): 2920, 2855, 1584, 1384, 768, 740 cm^{-1}. GC-MS (EI) *m/z* = 194 $(M)^+$ for $C_{11}H_{14}OS$.

2-((2,4-Dimethylphenoxy)methyl)thiirane (1g)

Colorless oil, 250 mg, yield 22%, R_f = 0.39 (Hexanes/EtOAc = 20:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.97 (d, *J* = 2.2 Hz, 1H), 6.93 (d, *J* = 8.2 Hz, 1H), 6.71 (d, *J* = 8.2 Hz, 1H), 4.19 (dd, *J* = 10.3, 5.4 Hz, 1H), 3.90 (dd, *J* = 10.4, 7.0 Hz, 1H), 3.31 – 3.25 (m, 1H), 2.60 (d, *J* = 6.2 Hz, 1H), 2.32 (dd, *J* = 5.3, 1.3 Hz, 1H), 2.26 (s, 3H), 2.23 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 154.5, 131.6, 130.3, 126.9, 111.9, 73.1, 31.7, 23.9, 20.4, 16.1. IR (KBr): 2920, 2853, 1560, 1503, 1383 cm^{-1}. GC-MS (EI) *m/z* = 194 $(M)^+$ for $C_{11}H_{14}OS$.

2-Methyl-2-[(3-methylphenoxy)methyl]thiirane (1m)

Colorless oil, 1.02 g, yield 57%, R_f = 0.73 (Hexanes/EtOAc = 10:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.16 (t, *J* = 7.6 Hz, 1H), 6.78 (d, *J* = 7.2 Hz, 1H), 6.73 – 6.68 (m, 2H), 4.15 (d, *J* = 9.6 Hz, 1H), 3.86 (d, *J* = 9.6 Hz, 1H), 2.52 (d, *J* = 1.0 Hz, 1H), 2.46 (t, *J* = 1.0 Hz, 1H), 2.32 (s, 3H), 1.74 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 158.7, 139.6, 129.2, 121.9, 115.6, 111.5, 76.0, 42.4, 32.7, 23.4, 21.5. IR (KBr): 2920, 2854, 1561, 1504, 1383 cm^{-1}. GC-MS (EI) *m/z* = 194 $(M)^+$ for $C_{11}H_{14}OS$.

General procedure for the preparation of thiiranes 1h–1j, 1k-l[8b]

To a stirring solution of oxirane **4** (10 mmol) in MeOH (30 mL) was added thiourea (1.52 g, 20 mmol); when it was completely dissolved, the resulting solution was refluxed for 1.5 h, After removal of solvent, H_2O (20 mL) was added. The solution was extracted with CH_2Cl_2 (3 x 15 mL) and the combined organic extracts were dried (Na_2SO_4). The solvent was removed under reduced pressure and the residue was purified by flash chromatography (Et_3N-neutralized silica gel, hexanes-EtOAc, 20:1, *v/v*) to afford thiirane **1** in moderate to good yields.

2-((Naphthalen-1-yloxy)methyl)thiirane (1h)

Colorless oil, 700 mg, yield 65%, R_f = 0.70 (Hexanes/EtOAc = 20:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.37 – 8.34 (m, 1H), 7.85 – 7.82 (m, 1H), 7.54 – 7.47 (m, 3H), 7.38 (t, *J* = 7.9 Hz, 1H), 6.81 (d, *J* = 7.6 Hz, 1H), 4.39 (dd, *J* = 10.2, 5.5 Hz, 1H), 4.12 (dd, *J* = 10.2, 6.9 Hz, 1H), 3.47 – 3.41 (m, 1H), 2.68 (d, *J* = 6.2 Hz, 1H), 2.43 (dd, *J* = 5.2, 1.2 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 154.1, 134.5, 127.4, 126.5, 125.7, 125.6, 125.3, 122.0, 120.8, 105.1, 72.7, 31.4, 23.9. IR (KBr): 2925, 2866, 1595, 1508, 1461, 771, 738 cm^{-1}. GC-MS (EI) *m/z* = 216 $(M)^+$ for $C_{13}H_{12}OS$.

2-((Naphthalen-2-yloxy)methyl)thiirane (1i)

White solid. mp 80 – 81 °C. 770 mg, yield 72%, R_f = 0.55 (Hexanes/EtOAc = 20:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.77 (dd, *J* = 8.5, 5.8 Hz, 2H), 7.72 (d, *J* = 8.2 Hz, 1H), 7.45 (ddd, *J* = 8.2, 6.8, 1.3 Hz, 1H), 7.36 (ddd, *J* = 8.1, 6.8, 1.3 Hz, 1H), 7.20 – 7.17 (m, 1H), 7.13 (d, *J* = 2.5 Hz, 1H). 4.34 (dd, *J* = 10.1, 5.5 Hz, 1H), 4.03 (dd, *J* = 10.2, 7.1 Hz, 1H), 3.40 – 3.31 (m, 1H), 2.65 (d, *J* = 6.2 Hz, 1H), 2.38 (dd, J = 5.2, 1.4 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 156.3, 134.4, 129.6, 129.1, 127.6, 126.8, 126.4, 123.8, 118.7, 107.0, 72.6, 31.3, 24.0. GC-MS (EI) *m/z* = 216 $(M)^+$ for $C_{13}H_{12}OS$.

2-(((6-Bromonaphthalen-2-yl)oxy)methyl)thiirane (1j)

White solid. mp 95 – 96 °C. 1.22 g, yield 83%, R_f = 0.61 (Hexanes/EtOAc = 20:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.92 (d, *J* = 1.9 Hz, 1H), 7.66 (d, *J* = 9.0 Hz, 1H), 7.58 (d, *J* = 8.7 Hz, 1H), 7.50 (dd, *J* = 8.7, 2.0 Hz, 1H), 7.19 (dd, *J* = 9.0, 2.5 Hz, 1H), 7.08 (d, *J* = 2.5 Hz, 1H), 4.31 (dd, *J* = 10.1, 5.6 Hz, 1H), 4.03 (dd, *J* = 10.1, 7.0 Hz, 1H), 3.36 – 3.30 (m, 1H), 2.65 (d, *J* = 6.1 Hz, 1H), 2.37 (dd, *J* = 5.3, 1.5 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 156.6, 132.9, 130.2, 129.7, 129.7, 128.7, 128.4, 119.8, 117.3, 106.9, 72.6, 31.2, 23.9. IR (KBr): 2924, 1588, 1498 cm^{-1}. GC-MS (EI) *m/z* = 294 $(M)^+$ for $C_{13}H_{11}BrOS$.

2-((4-Chlorophenoxy)methyl)thiirane (1k)

Colorless oil, 1.89 g, yield 47%, R_f = 0.56 (Hexanes/EtOAc = 10:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.15 (d, *J* = 8.4 Hz, 2H), 6.77 (d, *J* = 8.4 Hz, 2H), 4.13 (dd, *J* = 10.8, 2.0 Hz, 1H), 3.82 (dd, *J* = 10.8, 5.6 Hz,

1H), 3.28 – 3.24 (m, 1H), 2.82 (t, *J* = 4.4 Hz, 1H), 2.67 – 2.66 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 157.0, 129.3, 126.1, 115.9, 69.0, 50.0, 44.5. GC-MS (EI) *m/z* = 200 $(M)^+$ for C_9H_9ClOS.

2-((4-Bromophenoxy)methyl)thiirane (1l)

Colorless oil, 407 mg, yield 32%, R_f = 0.66 (Hexanes). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.38 (d, *J* = 8.8 Hz, 2H), 6.79 (d, *J* = 8.9 Hz, 2H), 4.15 (dd, *J* = 10.2, 5.6 Hz, 1H), 3.89 (dd, *J* = 10.2, 6.9 Hz, 1H), 3.28 – 3.22 (m, 1H), 2.61 (d, *J* = 6.1 Hz, 1H), 2.31 (dd, *J* = 5.3, 1.4 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 157.5, 132.3, 116.5, 113.4, 72.8, 31.1, 23.8. GC-MS (EI) *m/z* = 244 $(M)^+$ for C_9H_9BrOS.

2-Methyl-2-((naphthalen-2-yloxy)methyl)thiirane (1n)

White solid; mp 60 – 61 °C. 863 mg, yield 75%, R_f = 0.71 (Hexanes/EtOAc = 20:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.79 – 7.75 (m, 2H), 7.72 (d, *J* = 8.2 Hz, 1H), 7.45 (t, *J* = 7.5 Hz, 1H), 7.35 (t, *J* = 7.5 Hz, 1H), 7.20 (d, *J* = 8.9 Hz, 1H), 7.11 (s, 1H), 4.29 (d, *J* = 9.6 Hz, 1H), 4.02 (d, *J* = 9.6 Hz, 1H), 2.56 (d, *J* = 26.7 Hz, 1H), 1.81 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 156.6, 134.4, 129.5, 129.1, 127.6, 126.7, 126.4, 123.8, 118.8, 107.0, 76.1, 42.3, 32.7, 23.5. IR (KBr): 2983, 2927, 1600, 1510, 1465, 1389 cm^{-1}. GC-MS (EI) *m/z* = 230 $(M)^+$ for $C_{14}H_{14}OS$.

Synthesis of thiirane 1o[9]

In a 100 mL round bottom flask, naphthalen-2-ol (7.64 g, 53.0 mmol) was dissolved in 30 mL of butanone and the mixture was stirred at room temperature. K_2CO_3 (11.06 g, 80.0 mmol) and KI (0.83 g, 5.0 mmol) were added to the mixture, followed by addition of 3-chloro-2-butanone (5.65 g, 53.0 mmol). The reaction mixture was then maintained under stirring for 12 h. After this time, the precipitate was removed under filtration and rinsed with ethyl acetate, and the organic phase was washed with water, and then with saturated KOH solution until the complete removal of unreacted naphthalen-2-ol. The combined organic phases were dried over anhydrous Na_2SO_4, concentrated and then dried under vocuum. The resulting product was used in the next step without further purification.

In a 50 mL round bottom flask, to a solution of potassium *tert*-butoxide (1.68 g, 15.0 mmol) in 10 mL of dimethylsulfoxide was added trimethylsulfoxonium iodide (3.63 g, 16.5 mmol) and stirred for 30 min at room temperature. The β-ketoether (3.21 g, 15 mmol) was added and the resulting solution was stirred overnight. The reaction mixture was diluted with EtOAc and water, and the layers were separated. The aqueous layer was back-extracted with EtOAc. The combined organic extracts were washed with brine and dried over Na_2SO_4. The solvent was removed under reduced pressure. The resulting product was used in the next step without further purification.

To a stirring solution of oxirane (1.14 g, 5 mmol) in MeOH (20 mL) was added thiourea (0.76 g, 10 mmol); when it was completely dissolved, the resulting soln was refluxed for 1.5 h, After removal of solvent, H_2O (20 mL) was added. The solution was extracted with CH_2Cl_2 (3 x 15 mL) and the combined organic extracts were dried (Na_2SO_4). The solvent was removed under reduced pressure and the residue was purified by flash chromatography (Et_3N-neutralized silica gel, hexanes-EtOAc, 20:1, *v/v*) to afford thiirane **1o** in 11% yield.

2-Methyl-2-(1-(naphthalen-2-yloxy)ethyl)thiirane (1o)

Colorless oil, 133 mg, yield 11%, R_f = 0.76 (Hexanes/EtOAc = 20:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.78 – 7.74 (m, 2H), 7.77 (d, *J* = 8.0 Hz, 1H), 7.44 (ddd, J = 8.2, 6.9, 1.2 Hz, 1H), 7.35 (ddd, *J* = 8.1, 6.8, 1.3 Hz, 1H), 7.18 – 7.14 (m, 2H), 4.11 (q, *J* = 6.4 Hz, 1H), 2.43 (d, *J* = 1.1 Hz, 1H), 2.34 (d, *J* = 1.3 Hz, 1H), 1.73 (s, 3H), 1.57 (d, *J* = 6.4 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 155.5, 134.4, 129.6, 129.2, 127.6, 126.7, 126.4, 123.9, 119.8, 110.0, 82.0, 46.3, 34.9, 20.0, 17.5. IR (KBr): 2982, 2930, 1629, 1599, 1509, 1377, 1254, 1215 cm^{-1}. GC-MS (EI) *m/z* = 244 $(M)^+$ for $C_{15}H_{16}OS$.

General procedure for the preparation of (2,3-dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanols 2

NBS (0.25 mmol) and thiirane **1** (0.25 mmol) were added in DMSO (5.0 mL) in a 10 mL microwave reaction tube, then the resulting solution was stirred at 110 °C for 15 mins under microwave irradiation in a sealed vessel. After cooling water (30 mL) was added, the mixture was extracted with DCM, and the combined extracts were washed with brine, dried over anhydrous sodium sulfate, and concentrated *in vacuo*, the resulting residue was purified by silica gel column chromatography (200-300 mesh, hexanes-EtOAc, 10:1, *v/v*) to afford the product **2**.

(2,3-Dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanol (2a)

Colorless oil, 19 mg, yield 42%, R_f = 0.26 (Hexanes/EtOAc = 3:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.06 – 7.03 (m, 1H), 7.02 – 6.70 (m, 1H), 6.89 – 6.83 (m, 2H), 4.49 (dd, *J* = 4.2, 11.8 Hz, 1H), 4.33 (dd, *J* = 2.2, 11.7 Hz, 1H), 3.87 (dd, *J* = 7.4, 11.3 Hz, 1H), 3.85 (dd, *J* = 6.8, 11.3 Hz, 1H), 3.41 (dddd, *J* = 4.3, 6.8, 2.2, 6.8 Hz, 1H), 1.76 (br s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 151.5, 127.5, 125.6, 122.0, 118.4, 116.7, 65.7, 62.6, 40.9. IR (KBr): 3440, 2925, 2873, 1477, 1071, 1032 cm^{-1}. GC-MS (EI) *m/z* = 182 $(M)^+$ for $C_9H_{10}O_2S$. HR-MS (ESI) *m/z* $[M + H]^+$ calcd for $C_9H_{11}O_3S^+$: 199.0423, found: 199.0426.

Under ESI condition, benzoxathiine always generates benzoxathiine S-oxide. Thus, the mass spectrum was determined under EI conditions for confirmation of structures.

(6-Methyl-2,3-dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanol (2b)

Colorless oil, 17 mg, yield 35%, R_f = 0.49 (Hexanes/EtOAc = 3:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.85 (s, 1H), 6.80 (d, *J* = 8.50, 1H), 6.73 (d, *J* = 8.50, 1H), 4.46 (dd, *J* = 4.2, 11.6 Hz, 1H), 4.29 (dd, *J* = 2.4, 11.3 Hz, 1H), 3.85 (dd, *J* = 7.6, 11.2 Hz, 1H), 3.84 (dd, *J* = 6.9, 11.4 Hz, 1H), 3.41 – 3.36 (m, 1H), 2.23 (s, 3H), 1.89 (br s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 149.3, 131.5, 127.6, 126.4, 118.1, 116.1, 65.7, 62.6, 40.8, 20.5. IR (KBr): 3403, 2923, 2876, 1601, 1490, 1393, 1065, 1026 cm^{-1}. GC-MS (EI) *m/z* = 196 $(M)^+$ for $C_{10}H_{12}O_2S$.

(7-Methyl-2,3-dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanol (2ca) and (5-methyl-2,3-dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanol (2cb)

Colorless oil, 20 mg, yield 41%, **2ca**:**2cb** = 1:3, R_f = 0.4 (Hexanes/EtOAc = 3:1, *v/v*). Major: ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 6.93 – 6.89 (m, 1H), 6.73 – 6.67 (m, 2H), 4.48 – 4.43 (m, 1H), 4.32 – 4.27 (m, 1H), 3.91 – 3.79 (m, 2H), 3.40 – 3.35 (m, 1H), 2.25 (s, 3H). Minor: ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 6.93 – 6.89 (m, 1H), 6.78 (d, *J* = 7.6 Hz, 1H), 6.73 – 6.67 (m, 1H), 4.48 – 4.43 (m, 1H), 4.32 – 4.27 (m, 1H), 3.91 – 3.79 (m, 2H), 3.47 – 3.42 (m, 1H), 2.23 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): *δ* 151.2, 135.8, 135.7, 134.0, 127.3, 124.6, 123.2, 123.0, 118.9, 118.5, 115.8, 112.8, 65.8, 65.2, 62.7, 62.5, 40.8, 40.7, 20.8, 19.4. IR (KBr): 3389, 2925, 2878, 1566, 1488, 1066, 1026 cm^{-1}. GC-MS (EI) *m/z* = 196 $(M)^+$ for $C_{10}H_{12}O_2S$.

(8-Methyl-2,3-dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanol (2d)

Colorless oil, 13 mg, yield 27%, R_f = 0.44 (Hexanes/EtOAc = 3:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 6.91 – 6.86 (m, 2H), 6.77 (t, *J* = 7.4 Hz, 1H), 4.52 (dd, *J* = 11.6, 4.3 Hz, 1H), 4.34 (dd, *J* = 11.6, 2.3 Hz, 1H), 3.92 – 3.80 (m, 2H), 3.41 (dddd, *J* = 4.3, 6.8, 2.3, 6.8 Hz, 1H), 2.18 (s, 3H), 1.95 (dd, *J* = 7.1, 5.3 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$): 143.4, 127.7, 127.1, 125.1, 121.3, 65.8, 62.7, 41.1, 16.2. IR (KBr): 3372, 2925, 1587, 1378, 1067, 1025 cm^{-1}. GC-MS (EI) *m/z* = 196 $(M)^+$ for $C_{10}H_{12}O_2S$.

(6-Methoxy-2,3-dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanol (2e)

Colorless oil, 8 mg, yield 15%, R_f = 0.27 (Hexanes/EtOAc = 3:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 6.77 (d, *J* = 8.8 Hz, 1H), 6.58 – 6.56 (m, 2H), 4.45 (dd, *J* = 4.0, 11.6 Hz, 1H), 4.26 (d, *J* = 11.6 Hz, 1H), 3.89 (dd, *J* = 7.7, 11.7 Hz, 1H), 3.84 (dd, *J* = 6.9, 11.5 Hz, 1H), 3.73 (s, 3H), 3.42 – 3.37 (m, 1H), 1.85 (br s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$): *δ* 154.3, 145.6, 119.0, 117.3, 112.1, 111.5, 65.7, 62.7, 55.7, 41.0. IR (KBr): 3432, 2928, 1602, 1508, 1062, 1032 cm^{-1}. GC-MS (EI) *m/z* = 212 $(M)^+$ for $C_{10}H_{12}O_3S$.

(7,8-Dimethyl-2,3-dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanol (2f)

Colorless oil, 35 mg, yield 66%, R_f = 0.39 (Hexanes/EtOAc = 3:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 6.80 (d, *J* = 7.9 Hz, 1H), 6.69 (d, *J* = 7.9 Hz, 1H), 4.51 (dd, *J* = 4.3, 11.6 Hz, 1H), 4.31 (d, *J* = 2.0, 11.8 Hz, 1H), 3.91 – 3.79 (m, 2H), 3.40 (dddd, *J* = 4.2, 2.3, 6.8, 6.8 Hz, 1H), 2.21 (s, 3H), 2.11 (s, 3H), 1.95 (dd, *J* = 5.4, 7.4 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$): *δ* 134.3, 126.2, 124.0, 123.1, 113.2, 105.0, 69.6, 67.3, 40.9, 19.8, 11.7. IR (KBr): 3450, 2925, 1655, 1384, 1075, 1032 cm^{-1}. GC-MS (EI) *m/z* = 210 $(M)^+$ for $C_{10}H_{12}O_3S$.

(6,8-Dimethyl-2,3-dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanol (2g)

Colorless oil, 23 mg, yield 43%, R_f = 0.43 (Hexanes/EtOAc = 3:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 6.70 (s, 1H), 6.68 (s, 1H), 4.49 (dd, *J* = 4.2, 11.6 Hz, 1H), 4.30 (d, *J* = 2.3, 11.6 Hz, 1H), 3.91 – 3.79 (m, 2H), 3.39 (dddd, *J* = 4.2, 2.3, 6.9, 6.9 Hz, 1H), 2.19 (s, 3H), 2.15 (s, 3H), 1.93 (dd, *J* = 5.3, 7.2 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$): *δ* 130.7, 128.0, 125.0, 122.4, 65.8, 62.7, 41.1, 20.4, 16.1. IR (KBr): 3366, 2922, 1478, 1377, 1070, 1025 cm^{-1}. GC-MS (EI) *m/z* = 210 $(M)^+$ for $C_{10}H_{12}O_3S$.

(2,3-Dihydronaphtho[1,2-*b*][1,4]oxathiin-3-yl)methanol (2h)

Colorless oil, 34 mg, yield 59%, R_f = 0.25 (Hexanes/EtOAc = 3:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 8.10 (d, *J* = 8.2 Hz, 1H), 7.72 (d, *J* = 7.9 Hz, 1H), 7.48 – 7.36 (m, 3H), 7.09 (d, *J* = 8.6 Hz, 1H), 4.72 (dd, *J* = 3.8, 11.8 Hz, 1H), 4.49 (d, *J* = 11.8 Hz, 1H), 3.95 (dd, *J* = 8.1, 11.3 Hz, 1H), 3.89 (dd, *J* = 7.0, 11.2 Hz, 1H), 3.56 – 3.51 (m, 1H), 1.93 (br s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$): *δ* 146.2, 132.1, 127.6, 126.0, 125.9, 125.5, 125.4, 121.4, 120.6, 110.6, 65.9, 62.6, 41.0. IR (KBr): 3381, 2927, 2879, 1622, 1588, 1397, 1050, 1023 cm^{-1}. GC-MS (EI) *m/z* = 232 $(M)^+$ for $C_{13}H_{12}O_2S$.

(2,3-Dihydronaphtho[2,1-*b*][1,4]oxathiin-2-yl)methanol (2i)

Colorless oil, 34 mg, yield 59%, R_f = 0.25 (Hexanes/EtOAc = 3:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 7.87 (d, *J* = 8.4 Hz, 1H), 7.75 (d, *J* = 8.1 Hz, 1H), 7.52 (d, *J* = 9.2 Hz, 1H), 7.51 (ddd, *J* = 8.4, 6.9, 1.3 Hz, 1H), 7.39 (ddd, *J* = 8.0, 6.9, 1.1 Hz, 1H), 7.05 (d, *J* = 8.9 Hz, 1H), 4.60 (dd, *J* = 11.5, 4.2 Hz, 1H), 4.45 (dd, *J* = 11.5, 2.2 Hz, 1H), 3.97 – 3.87 (m, 2H), 3.57 (dddd, *J* = 2.3, 4.2, 6.8, 6.8 Hz, 1H), 2.02 (dd, *J* = 7.0, 5.3 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$): *δ* 149.1, 131.2, 129.6, 128.4, 126.4, 125.8, 124.3, 122.1, 119.6, 109.44, 65.6, 62.5, 40.3. IR (KBr): 3423, 2964, 2926, 1619, 1567, 1051, 1026 cm^{-1}. GC-MS (EI) *m/z* = 232 $(M)^+$ for $C_{13}H_{12}O_2S$.

(8-Bromo-2,3-dihydronaphtho[2,1-*b*][1,4]oxathiin-2-yl)methanol (2j)

Colorless oil, 34 mg, yield 44%, R_f = 0.28 (Hexanes/EtOAc = 3:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 7.90 (d, *J* = 2.0 Hz, 1H), 7.73 (d, *J* = 9.0 Hz, 1H), 7.55 (dd, *J* = 9.0, 2.0 Hz, 1H), 7.42 (d, *J* = 8.9 Hz, 1H), 7.06 (d, *J* = 8.9 Hz, 1H), 4.59 (dd, *J* = 11.5, 4.2 Hz, 1H), 4.44 (dd, *J* = 11.5, 2.2 Hz, 1H), 3.93 (dd, *J* = 10.3, 6.5 Hz, 1H), 3.89 (dd, *J* = 10.3, 5.9 Hz, 1H), 3.56 (dddd, *J* = 2.1, 4.2, 6.8, 6.8 Hz, 1H), 2.00 (br s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$): *δ* 149.3, 130. 8, 130.3, 129.8, 129.6, 124.8, 124.0, 120.7, 118.0, 110.0, 65.6, 62.5, 40.2. IR (KBr): 3431, 2926, 2877, 1588, 1390, 1074, 500 cm^{-1}. GC-MS (EI) *m/z* = 310 $(M)^+$ for $C_{13}H_{11}BrO_2S$.

(3,7-Dimethyl-2,3-dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanol (2ma) and (3,5-dimethyl-2,3-dihydrobenzo[*b*][1,4]oxathiin-3-yl)methanol (2mb)

Colorless oil, 6 mg, yield 12%, **2ma**:**2mb** = 1:2, R_f = 0.66 (Hexanes/EtOAc = 3:1, *v/v*). Major: ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 7.94 – 6.89 (m, 1H), 6.79 – 6.69 (m, 2H), 4.34 (d, *J* = 11.6 Hz, 1H), 3.94 (d, *J* = 11.6 Hz, 1H), 3.77 – 3.71 (m, 1H), 3.66 – 3.62 (m, 1H), 2.26 (s, 3H). 1.83 (br s, 1H), 1.37 (s, 3H). Minor: ^{1}H NMR (400 MHz, $CDCl_3$): *δ* 7.94 – 6.89 (m, 1H), 6.79 – 6.69 (m, 2H), 3.94 (d, *J* = 11.5 Hz, 1H), 3.91 (d, *J*= 11.6 Hz, 1H), 3.77 – 3.71 (m, 1H), 3.66 – 3.62 (m, 1H), 2.22 (s, 3H), 1.83 (br s, 1H), 1.41 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) *δ* 127.0, 124.6, 123.2, 123.0, 118.7, 115.6, 71.0, 70.4, 66.8, 66.6, 47.2, 45.0, 20.9, 19.5. IR (KBr): 3434, 2925, 1608, 1379, 1052, 1029 cm^{-1}. GC-MS (EI) *m/z* = 210 $(M)^+$ for $C_{11}H_{14}O_2S$.

(3-Methyl-2,3-dihydronaphtho[2,1-*b*][1,4]oxathiin-2-yl)methanol (2n)

Golden yellow oil, 21 mg, yield 45%, R_f = 0.53 (Hexanes/EtOAc = 3:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.77 (d, *J* = 8.3 Hz, 1H), 7.68 (d, *J* = 8.1 Hz, 1H), 7.45 (d, *J* = 8.7 Hz, 1H), 7.42 (ddd, *J* = 1.4, 6.7, 8.2 Hz, 1H), 7.31 (ddd, *J* = 1.1, 6.9, 8.0 Hz, 1H), 7.00 (d, *J* = 9.1 Hz, 1H), 4.39 (d, *J* = 11.4 Hz, 1H), 3.98 (d, *J* = 11.4 Hz, 1H), 3.71 (d, *J* = 11.5 Hz, 1H), 3.62 (d, *J* = 11.3 Hz, 1H), 1.87 (br s, 1H), 1.41 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 148.1, 131.0, 128.4, 126.4, 125.7, 124.2, 122.2, 119.3, 110.4, 105.0, 70.8, 66.5, 44.6, 21.0. IR (KBr): 3437, 2926, 2877, 1618, 1502, 1228, 1074, 1022 cm^{-1}. GC-MS (EI) *m/z* = 246 $(M)^+$ for $C_{14}H_{14}O_2S$.

(2,3-Dimethyl-2,3-dihydronaphtho[2,3-*b*][1,4]oxathiin-3-yl)methanol (2o)

Grass green oil, 20 mg, yield 31%, R_f = 0.57 (Hexanes/EtOAc = 3:1, *v/v*). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.87 (d, *J* = 8.4 Hz, 1H), 7.75 (d, *J* = 8.1 Hz, 1H), 7.53 (d, *J* = 9.1 Hz, 1H), 7.50 (ddd, *J* = 1.3, 7.0, 8.2 Hz, 1H), 7.38 (ddd, *J* = 1.0, 6.9, 8.0 Hz, 1H), 7.06 (d, *J* = 8.9 Hz, 1H), 4.43 (q, *J* = 6.6 Hz, 1H), 3.83 (d, *J* = 10.8 Hz, 1H), 3.74 – 3.69 (m, 1H), 1.95 (d, *J* = 6.9 Hz, 1H), 1.51 (s, 3H), 1.50 (d, *J* = 6.6 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 148.8, 131.0, 129.5, 128.4, 126.4, 125.9, 124.1, 122.4, 119.4, 110.4, 77.9, 64.3, 49.2, 22.1, 15.9. IR (KBr): 3429, 1596, 1460, 1384, 1234 cm^{-1}. GC-MS (EI) *m/z* = 260 $(M)^+$ for $C_{15}H_{16}O_2S$.

Conflicts of interest

There are no conflicts to declare.

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