Synthesis of possible *o*-thioquinone methide precursors

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Abstract: Investigating the synthetic accessibility of *o*-thioquinone methide precursors containing electron donating groups, we prepared four methyl- and methoxy-substituted 2*H*-benzo[b]thiete derivatives by means of flash vacuum pyrolysis of the corresponding benzooxathiinone species. Methyl- and methoxy-substituted substrates proved to be compatible with the pyrolysis protocol. The pyrolysis can be performed at considerably lower temperatures and with higher yields than in previously reported syntheses of nonsubstituted 2*H*-benzo[b]thiete. Under proper conditions the reaction products can be isolated in excellent yields and with 100% purity, so the troublesome purification of temperature sensitive and volatile 2*H*-benzo[b]thiete derivatives becomes unnecessary. The sulfur-containing compounds so obtained are efficient *o*-thioquinone methide precursors and possible synthones for heterocyclic chemistry.

Key words: 2*H*-benzo[b]thietes, flash vacuum pyrolysis, methyl-substituted, methoxy-substituted, *o*-thioquinone methide precursors.

Résumé : Dans le cadre de nos travaux sur l'accessibilité synthétique de précurseurs de méthides de *o*-thioquinone contenant des groupes électrodonneurs, on a préparé quatre dérivés du 2*H*-benzo[b]thiète substitués par des groupes méthyles et méthoxy en faisant appel à la pyrolyse éclair sous vide des espèces benzooxathiinones correspondantes. Il est possible d'effectuer les pyrolyses à des températures beaucoup plus basses et avec de meilleurs rendements que ceux rapportés antérieurement pour les 2*H*-benzo[b]thiètes non substitués. Dans les bonnes conditions, les produits de la réaction peuvent être isolés avec d'excellents rendements et une pureté de 100, ce qui rend inutile la purification des dérivés 2*H*-benzo[b]thiètes volatils et sensibles à la température. Les composés contenant du soufrant ainsi obtenus sont des précurseurs efficaces de méthides de *o*-thioquinone et pourraient servir de synthons en chimie hétérocyclique.

Mots-clés : 2*H*-benzo[b]thiètes, pyrolyse éclair sous vide, substitué par un méthyle, substitué par un méthoxy, précurseurs de méthides de *o*-thioquinone

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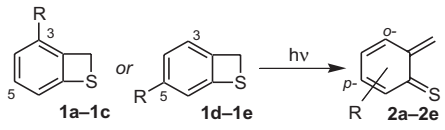
Introduction

Quinone methides and their far less studied sulfur analogs are interesting molecules with wide application in organic synthesis (1). Extending our investigation of quinone methides generated by flash photolysis to sulfur-containing species, we synthesized some substituted 2*H*-benzo[b]thiete derivatives (Scheme 1, structure **1**) as possible precursors of *o*-thioquinone methides (Scheme 1, structure **2**). In our previous research (2), we had established that 2*H*-benzo[b]thiete (**1a**, R = H), containing a strained four-membered ring, is a good precursor for clean and high-yielding photo-generation of **2a** (R = H), needed for accurate kinetic measurements of its hydration in aqueous solution by means of flash photolytic methods. *o*-Thioquinone methide (**2a**, R = H) proved to be quite short-lived in aqueous solutions (2). Expecting to obtain transients **2** with considerably longer lifetimes, we were particularly interested in the preparation of compounds **1** containing electron donating groups at 3- or 5- positions, which would correspond to ortho and para positions, respectively, in the "thioquinone" ring of **2**, relative to the methylene group.

Scheme 1.



R = H, 3- *or* 5-Me, 3- *or* 5-MeO

Despite the merits of the 2*H*-benzo[b]thiete molecule, no compounds of type **1** *substituted in the benzene ring* have been described previously. The few known syntheses of **1a** made use of flash vacuum pyrolysis (FVP) at very high temperatures (700–1200 °C (3*a*–3*c*)), and no mention was made of substituted precursors (R = Me, MeO) that could be used in the synthetic procedures.

One could get the impression that because of the drastic reaction conditions of FVP, the synthesis of substituted 2*H*-benzo[b]thietes was unfeasible. Also, it is known that methyl- and methoxy-substituted aromatic hydrocarbons, including such simple derivatives as toluene and anisole,

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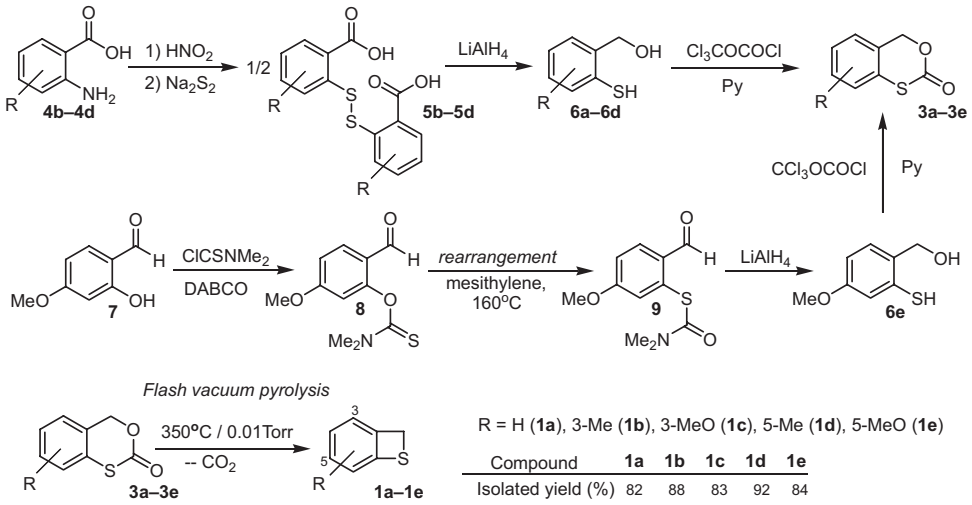
Scheme 2. (1 torr = 133.322 4 Pa)



undergo demethylation when exposed to high temperatures (typically above 700 °C); soot and many other products are formed depending on conditions of the gas-phase pyrolysis (4). Finally, the existing syntheses of **1a** leave much to be improved.

According to H. Meier and A. Mayer (3*d*), 4*H*-benzo[d][1,3]oxathiin-2-one (Scheme 2, compound **3a**, R = H) undergoes decarboxylation at 140 °C already and therefore can be used as a synthetic equivalent of 2*H*-benzo[b]thiete (**1a**, R = H) in some reactions. Nonetheless, in the course of the preparative synthesis of **1a** via pyrolysis of **3a**, the authors maintained a rather high (550 °C) temperature (3*d*). We decided to check if the pyrolysis temperature could be considerably decreased. The lower the temperature, the better the chances are to obtain the derivatives of **1** in greater diversity, and, also importantly, utilize a pyrex apparatus instead of the traditionally used quartz. We explored the synthetic accessibility of *o*-thioquinone methide precursors of structure **1** containing methyl and methoxy groups. Now that the synthetic part of our research is complete, we wish to report the properties of the novel 2*H*-benzo[b]thiete derivatives and details of the syntheses.

Results and discussion

In our syntheses of compounds **1b**–**1e**, we decided to follow the route described by H. Meier and A. Mayer (5) for **1a**, which involved the preparation of the 4*H*-benzo[d][1,3]oxathiin-2-one (Scheme 2, **3a**, R = H) followed by decarboxylation performed under FVP conditions. As seen in Scheme 2, compounds **3b**–**3e** were obtained from the corresponding 2-mercaptobenzyl alcohols (**6a**–**6e**) by the reaction with trichloromethyl chloroformate (diphosgene). The alcohols **6**, of which all except **6a** are new compounds, were prepared from the commercially available substituted 2-aminobenzoic acids (**4a**–**4d**). The first stage of the syntheses involved a simplified Leukart reaction, which is known to provide good yields for 2,2′-dithiosalicylic acid **5a** and its methyl and methoxy derivatives **5b**–**5d** (5). The diazotization of the amino groups in **4a**–**4d** was followed by decomposition in aqueous solutions of sodium disulfide, and the disulfides **5a**–**5d** were reduced with a large excess of $LiAlH_4$, as described (6) for **5a** (R = H). On the other hand, the synthesis of 4-methoxy derivative (**6e**, R = 4-MeO) involved a Newman–Kwart reaction (7) on the commercially available 2-hydroxy-4-methoxybenzaldehyde (Scheme 2, **7**) followed by reduction (see the Experimental section for details).

Flash vacuum pyrolysis (FVP) generally involves controlled vaporization of neat compounds in vacuo and vapor passage through tube type reactors maintained at high temperatures (3–6). The initial experiments on the compound **3a** as a substrate gave promising results. First, we established that the flash vacuum pyrolysis does occur at considerably lower temperatures (i.e., 250–300 °C) than H. Meier and A. Mayer suggest (550 °C). Further, we found that the decarboxylation in this temperature range is selective. Apart from **1a**, the unreacted starting material **3a** was detected as the only impurity in some experiments (at low pyrolysis temperatures and with high substrate sublimation rates). This means that, under the right conditions, the reaction product can be collected pure, which is a great advantage considering the instability and volatility of 2*H*-benzo[b]thiete. The latter usually poses difficulties when solvents are being evaporated from dilute compound solutions — for example, after chromatographic separation in the final purification stage.

Besides the reaction temperature, another important parameter of the process is the so-called "contact time", which indicates how long the compound vapor is exposed to high temperature in the reactor. This depends on the length of the reaction tube and (or) substrate sublimation rate. Despite 100% selectivity achieved for the gas phase pyrolysis itself, all the compounds **3**, including the nonsubstituted **3a**, proved temperature sensitive and underwent polymerization to a noticeable extent even at 30–40 °C. Therefore, there is a limit to the sublimation temperature and consequently the process output. When we switched to methyl and methoxy derivatives **3b**–**3e** as substrates, we found that their volatility was 3–5 times lower than that of **3a**. As expected, the introduction of substituents into the small molecule **3a** drastically decreased the volatility. With the apparatus we had at our disposal and under high vacuum (0.005–0.010 torr, 1 torr = 133.322 4 Pa), the process output was some 1–1.5 mg/h.

With lower substrate sublimation rates and consequently longer contact times, temperature variations in the 300–450 °C range did not affect either yield or purity of the products. All the compounds were isolated in the pure state (~99%, HPLC, NMR) and in excellent yields (82–92%, see Scheme 2). The general procedure for flash vacuum pyrolysis is described in the Experimental section. The four derivatives **1b**–**1e** were characterized by ^{1}H and ^{13}C NMR, high- and low-resolution mass spectrometry, and by melting points.

In the NMR spectra of **1b**–**1e** at 4.30–4.40 ppm (^{1}H) and at 35.10–36.55 ppm (^{13}C), signals were observed that could be unmistakeably attributed to methylene groups (CH_2) in the four-membered ring. As expected, those signals were markedly shifted upfield, compared with that of oxymethylene groups (OCH_2) in oxathiinone precursors **3b**–**3e** (5.10–4.50 ppm (^{1}H) and 66.60–72.60 ppm (^{13}C), respectively). The latter compounds also develop "carbonyl" signals resonating in the low-field area at 166–168 ppm (^{13}C). Also, in proton NMR spectra of compounds **1b** and **1c**, one could observe the typical picture of meta-substituted benzene rings with well-resolved singlets and doublets (see Experimental section for NMR spectroscopic data).

It should be noted that compounds **1b**–**1e** proved much more temperature sensitive, especially in solutions, than the nonsubstituted compound **1a**. Polymerization of **1a** has been described in the literature (4c), and polymerization of the derivatives **1b**–**1e** was evidenced in our research by the formation of insoluble precipitates upon storage (even at –10 °C). In addition, chromatographic analyses showed a decrease in compound concentration, while no other products were detected (polymers could not pass through the column we have used for the analysis of compounds **2** and **3**; see Experimental section for details).

Conclusions

Four methyl- and methoxy-substituted 2*H*-benzo[b]thietes **1b**–**1e** were synthesized in excellent yields from the corresponding 4*H*-benzo[d][1,3]oxathiin-2-ones **3b**–**3e** via flash vacuum pyrolysis. The process was a substantial improvement on the previously reported syntheses of **3a**. Particularly, we showed that the pyrolysis can be performed at considerably lower temperatures (300 °C), which allows the use of pyrex instead of quartz in the apparatus. Our experiments demonstrated that methyl- and methoxy-substituted substrates are compatible with the pyrolysis protocol. Under proper conditions, the reaction products can be isolated in excellent yields and with a very high purity. The final purification step is thus avoided, which is very important in dealing with the temperature sensitive and volatile 2*H*-benzo[b]thiete derivatives.

Experimental section

General

Substituted 2-aminobenzoic acids (**4b**–**4d**) were purchased from Peakdale Molecular (UK), and the rest of the chemicals from Aldrich. Progress of the reactions was monitored either by HPLC using a 5500 Varian Vista chromatograph equipped with Waters Symmetry C-18 reverse-phase column (4.6/150 mm, 5 μ particle size, methanol/water (50:50 vol.) as mobile phase) or by or TLC on silica gel SIL G/UV 254 plates developed in hexane. Mass spectra were recorded on a Micromass 70S-250 sector mass spectrometer and NMR spectra on a Varian spectrometer at 300 MHz (^{1}H) and 75 MHz (^{13}C). All the solvents, including THF and pyridine, were freshly distilled and dried by conventional methods.

Flash vacuum pyrolysis — General procedure for the preparation of 2*H*-benzo[b]thiete derivatives (1a–1e).

The apparatus for flash vacuum pyrolysis consisted of a test tube for sublimation connected to a pyrex reactor (2.5 cm × 35 cm) placed inside a tube furnace. The oxathiinone precursors (30–50 mg) were dissolved in ~2 mL of methylene chloride and the solutions were evaporated inside the test tube under an argon purge to achieve better coverage of its inner surface by the solids, which assisted sublimation. The test tube was mainained at 30–35 °C by means of external heating. The vacuum was maintained at 0.005–0.010 torr by means of a rotary pump. The products were condensed in a trap, cooled with liquid nitrogen, and handled uner inert atmosphere. In a typical experiment, about 20 mg of a compound **1a**–**1e** was isolated.

General procedure for the preparation of 4*H*-benzo[d][1,3]oxathiin-2-one derivatives (3a–3e)

To a stirred solution of the thiol substrates (2 mmol) and pyridine (470 mg, 6 mmol) in 40 mL of THF, trichloromethylchlorocarbonate (260 mg, 1.30 mmol) in 5 mL of THF was added at –5 °C in 20 min under an argon atmosphere. Further, 0.5 mL of concd. HCl in 50 mL of water, 50 mL of saturated brine, 25 mL of hexane, and 5 mL of methylene chloride was added successively upon stirring at RT. The organic layer was separated, and the aqueous layer was extracted with a mixture of hexane (25 mL) and methylene chloride (5 mL). Combined extracts were washed with 15 mL of water and then with a solution of 28 mg (0.5 mmol) KOH in 10 mL of water. The extracts were dried over $MgSO_4$, and the solvents were evaporated under reduced pressure. Crude products were purified by column chromatography over a short column containing ~8 g of silica gel with methylene chloride/hexane (1:2 vol.) as liquid phase.

2-Mercaptobenzyl alcohols (6b–6d)

The compounds **6b**–**6d**were obtained by reduction of the corresponding dithiosalicylic acids **5b**–**5d** (Scheme 2), themselves prepared via a simplified Leukart reaction on 2-aminobenzoic acids (**4b**–**4d**) in good yields, according to known procedures (5*b* and 5*c*). The identity of the products identity was confirmed by melting point determination and by ^{1}H NMR spectroscopy. The most recent report on the preparation of 2-mercaptobenzyl alcohol **6a** (R = H) belongs to A. Arnoldi and M. Carughi (6), who used it as an intermediate without purification. Our recipe for the preparation of **6b**–**6d** is very simple and, more importantly, provides very high purities (~99%, HPLC) for all the produts. In a typical experiment, the reduction was carried out as follows: To an ice-cooled solution of the dithiosalicylic acid substrate **5b**–**5d** (0.004 mol) in THF (60 mL), $LiAlH_4$ powder

(0.800 g, 0.021 mol) was added in a few portions upon stirring under an argon purge. The solution was slowly (~30 min) warmed up to RT, stirred for 1 h at 55–60 °C, cooled again, and carefully poured onto a mixture of ice (100 g) and 30 mL of 10 wt% H_2SO_4 upon vigorous stirring. Benzene (20 mL) was added immediately afterwards, and the organic layer separated. Water phase was extracted with benzene (20 mL × 2) and the combined organic extract was washed with water (15 mL) and a saturated $NaHCO_3$ solution (10 mL). From the benzene solution, the compounds **6b**–**6d** were extracted with NaOH (0.400 g, 0.010 mol) in 15 mL of water. The alkaline extract was acidified with concd. HCl (1.5 mL) and treated with CH_2Cl_2 (20 mL × 2). The organic phase was washed with brine (10 mL), dried and evaporated in vacuo. For the final purification, the alcohols were decolorized with silica gel (0.10 g) in methylene chloride/pentane (~1:10 vol.) solutions at RT, and crystallized upon cooling to (–20)–(+30) °C (because of their low melting points; properties and yields are reported later). All the compounds **6** are air-sensitive, and therefore all the manipulations were carried out under an argon atmosphere. The identity and purity of the alcohols **6b**–**6d** (all four are new compounds) was confirmed by ^1H and ^{13}C NMR spectroscopic data and mass spectrometry (see following).

2-Mercapto-6-methylbenzyl alcohol (6b)

Yield 67%. Colorless needles, mp 74–76 °C (methylene chloride/pentane). ^1H NMR ($CDCl_3$, ppm) δ: 1.84 (br s, 1H, OH) 2.41 (s, 3H, CH_3), 3.64 (s, 1H, SH), 4.88 (s, 2H, CH_2) 6.99–7.25 (m, $3H_{Ar}$). ^{13}C NMR ($CDCl_3$, ppm) δ: 19.72 (CH_3), 60.57 (CH_2OH), 128.52, 128.73, 129.39, 131.90, 136.72, 138.40. MS EI (70 eV) *m/z* (%): 154 (10, M^+), 136 (100, $M^+ - H_2O$), 121 (12, $M^+ - H_2O - CH_3$). HRMS (EI) calcd. for (M^+) $C_8H_{10}O_2S$: 154.0452; found: 154.0456.

2-Mercapto-6-methoxybenzyl alcohol (6c)

Yield 62%. Colorless needles, mp 68 to 69 °C (methylene chloride/pentane). ^1H NMR ($CDCl_3$, ppm) δ: 2.22 (br s, 1H, OH), 3.64 (s, 1H, SH), 3.83 (s, 3H, OCH_3), 4.66 (s, 2*H*, CH_2), 6.71–7.49 (m, $3H_{Ar}$). ^{13}C NMR ($CDCl_3$, ppm) δ: 55.70 (OCH_3), 58.26 (CH_2OH), 108.52, 123.62, 127.20, 129.16, 132.77, 158.40. MS EI (70 eV) *m/z* (%): 170 (15, M^+), 152 (100, $M^+ - H_2O$), 121 (20, $M^+ - H_2O - OCH_3$). HRMS (EI) calcd. for (M^+) $C_8H_{10}O_2S$: 170.0402; found: 170.0407.

2-Mercapto-4-methylbenzyl alcohol (6d)

Yield 73%. Colorless needles, mp 42 to 43 °C (methylene chloride/pentane). ^1H NMR ($CDCl_3$ ppm) δ: 1.85 (br s, 1H, OH) 2.30 (s, 3H, CH_3), 3.66 (s, 1H, SH), 4.69 (s, 2H, CH_2) 6.98 (d, *J* = 7Hz, $1H_{Ar}$), 7.19 (s, $1H_{Ar}$), 7.24 (d, *J* = 7Hz, $1H_{Ar}$). ^{13}C NMR ($CDCl_3$, ppm) δ: 20.91 (CH_3), 64.29 (CH_2OH), 127.19, 128.94, 130.13, 131.99, 135.89, 138.48. MS EI (70 eV) *m/z* (%): 154 (12, M^+), 136 (100, $M^+ - H_2O$), 121 (15, $M^+ - H_2O - CH_3$). HRMS (EI) calcd. for (M^+) $C_8H_{10}O_2S$: 154.0452; found: 154.0451.

2-Mercapto-4-methoxybenzyl

The alcohol (**6e**) was obtained via a Newman–Kwart reaction (see Scheme 2) on the commercially available 2-hydroxy-4-methoxybenzaldehyde (**7**) by the following steps.

Dimethylthiocarbamic acid *O*-(2-formyl-5-methoxyphenyl) ester (8)

A solution of *N*,*N*-dimethylthiocarbamoyl chloride (3.10 g, 0.025 mol), 2-hydrohy-4-methoxybenzaldehyde (3.04 g, 0.02 mol), and DABCO (3.02g, 0.027 mol) in 20 mL of anhyd. DMF was stirred overnight at RT for 2 h at 35–40 °C, and then poured into 200 mL of ice cold water. The yellow powder was collected, dried, and recrystallized from a benzene/hexane mixture (1:3 vol.) to afford 3.32 g (70%) of a colorless product whose melting point was 88 to 89 °C. ^1H NMR and mass spectra agreed with the structure **8**. ^1H NMR ($CDCl_3$, ppm) δ: 3.41, 3.47 (2s, 6H, NCH_3), 3.88 (s, 3H, OCH_3), 6.63 (s, $1H_{Ar}$), 6.90 (d, *J* = 6Hz, $1H_{Ar}$), 7.85 (d, *J* = 6Hz, $1H_{Ar}$), 9.92 (s, 1H, CHO). MS (ESI) *m/z* (%): 262 (100, M + Na^+), 239 (15, M + H^+), 212 (10, M^+ – CO). HRMS (ESI) calcd. for (M + Na^+) $C_{11}H_{13}O_3NaS$: 262.0508; found: 262.0501.

Dimethylcarbamic acid *S*-(2-formyl-5-methoxyphenyl) ester (9)

The rearrangement of the *O*-ester **8** to the corresponding *S*-ester **9** (see Scheme 2) was performed at 165 °C using mesithylene as solvent instead of the commonly used biphenyl ether (7b). Mesithylene proved much easier to remove and, more importantly, higher reaction temperatures (190–200 °C) are unsuitable for **8** because of its thermal sensitivity. Compound **8** (2.00 g, 0.008 mol) was refluxed in 20 mL of mesithylene for 25 h under an argon atmosphere. The rearrangement was monitored by TLC on silica plates using methylene chloride/acetone (10:1) as mobile phase. The solution was evaporated in a Petrie plate at atmospheric pressure, the residue dissolved in a methylene chloride/hexane (1:2 vol.) mixture (180 mL), decolorized with 0.40 g of silica gel, and crystallized to afford 1.65 g (80%) of pale yellow needles with mp 78 °C. ^1H NMR ($CDCl_3$, ppm) δ: 3.04, 3.16 (2s, 6H, NCH_3), 3.88 (s, 3H, OCH_3), 7.02 (s, $1H_{Ar}$), 7.05 (d, *J* = 6Hz, $1H_{Ar}$), 8.01 (d, *J* = 6Hz, $1H_{Ar}$), 10.27 (s, 1H, CHO). MS (ESI) *m/z* (%): 262 (100, M + Na^+), 239 (30, M + H^+), 212 (10, M^+ – CO), 167 (20, $M^+ - CON(CH_3)_2$). HRMS (ESI) calcd. for (M + Na^+) $C_{11}H_{13}O_3NaS$: 262.0508; found: 262.0504.

Compound **9** (0.956 g, 0.004 mol) in 5 mL of THF was added to a stirred suspension of LiAlH4 (0.800 g, 0.021 mol) in 30 mL of THF at 0 °C during 10 min under an argon purge, the reaction mixture was stirred for 4 h at 50°, and then treated exactly as described for the alcohols **6b**–**6d** (see earlier) to furnish **6e** (0.456 g, 67%) as colorless needles with mp 26–28 °C (methylene chloride/pentane). ^1H NMR ($CDCl_3$, ppm) δ: 1.84 (br s, 1H, OH) 3.78 (s, 3H, OCH_3), 3.90 (s, 1H, SH), 4.66 (s, 2H, CH_2) 6.64 (d, *J* = 7Hz, $1H_{Ar}$), 6.87 (s, $1H_{Ar}$), 7.22 (d, *J* = 7Hz, $1H_{Ar}$). ^{13}C NMR ($CDCl_3$, ppm) δ: 55.52 (OCH_3), 64.09 (CH_2OH), 111.81, 116.69, 130.45, 131.20, 132.14, 159.45. MS EI (70 eV) *m/z* (%): 170 (25, M^+), 152 (100, $M^+ - H_2O$), 121 (15, $M^+ - H_2O - OCH_3$). HRMS (EI) calcd. for (M^+) $C_8H_{10}O_2S$: 170.0402; found: 170.0401.

3-Methyl-2*H*-benzo[b]thiete (1b)

Yield 88%. Colorless liquid, fp (–10)–(+)9 °C. ^1H NMR (CD_3CN, ppm) δ: 2.27 (s, 3H, CH_3), 4,33 (s, 2H, CH_2), 6.91–6.98 (m, $2H_{Ar}$), 7,18–7.24 (m, $1H_{Ar}$). ^{13}C NMR

(CD_3CN, ppm) δ: 15.08 (CH_3), 35.88 (CH_2), 118.52, 125.42, 129.51, 133.12, 138.88, 142.46. MS EI (70 eV) *m/z* (%): 136 (100, M^+), 121 (20, $M^+ - CH_3$), 91 (45, $M^+ - S - CH_3$). HRMS (EI) calcd. for (M^+) C_8H_8S: 136.0347; found: 136.0348.

5-Methyl-4*H*-benzo[d][1,3]oxathiin-2-one (3b)

Yield 55%. Colorless needles, mp 64–66 °C. ^1H NMR (CD_3CN, ppm) δ: 2.44 (s, 3H, CH_3), 5.47 (s, 2H, CH_2), 7.23–7.27 (m, $2H_{Ar}$), 7.33–7.38 (m, $1H_{Ar}$). ^{13}C NMR (CD_3CN, ppm) δ: 18.31 (CH_3), 69.39 (CH_2), 124.44, 128.18, 129.73, 130.09, 131.18, 136.47, 167.20 (C=O). MS EI (70 eV) *m/z* (%): 180 (20, M^+), 136 (100, $M^+ - CO_2$), 121 (45, $M^+ - CO_2 - CH_3$). HRMS (EI) calcd. for (M^+) $C_9H_8O_2S$: 180.0245; found: 180.0248.

3-Methoxy-2*H*-benzo[b]thiete (1c)

Yield 83%. Colorless liquid, fp 11–13 °C. ^1H NMR (CD_3CN, ppm) δ: 3.95 (s, 3H, OCH_3), 4.41 (s, 2H, CH_2), 6.64–6.66 (m, $2H_{Ar}$), 7.21–7.26 (m, $1H_{Ar}$). ^{13}C NMR (CD_3CN, ppm) δ: 35.10 (CH_2), 56.05 (OCH_3), 109.76, 114.41, 124.12, 130.67, 143.96, 153.01 (C3). MS EI (70 eV) *m/z* (%): 152 (100, M^+), 137 (10, $M^+ - CH_3$), 121 (40, $M^+ - OCH_3$), 107 (15, $M^+ - CH_2 - OCH_3$). HRMS (EI) calcd. for (M^+) C_8H_8OS: 152.0296; found: 152.0299.

5-Methoxy-4*H*-benzo[d][1,3]oxathiin-2-one (3c)

Yield 63%. Colorless needles, mp 68 to 69 °C. ^1H NMR (CD_3CN, ppm) δ: 3.93 (s, 3H, CH_3), 5.49 (s, 2H, CH_2), 7.95–7.10 (m, $2H_{Ar}$), 7.41–7.49 (m, $1H_{Ar}$). ^{13}C NMR (CD_3CN, ppm) δ: 56.25 (OCH_3), 66.63 (CH_2), 110.82, 117.42, 118.56, 131.17, 132.34, 156.61 (C3), 166.88 (C=O). MS EI (70 eV) *m/z* (%): 196 (15, M^+), 152 (100, $M^+ - CO_2$), 121 (40, $M^+ - CO_2 - OCH_3$). HRMS (EI) calcd. for (M^+) $C_9H_8O_3S$: 196.0194; found: 196.0193.

5-Methyl-2*H*-benzo[b]thiete (1d)

Yield 92%. Colorless prisms, mp 54 to 55 °C. ^1H NMR (CD_3CN, ppm) δ: 2.35(s, 3H, CH_3), 4.32 (s, 2H, CH_2), 6.81 (d, J = 8Hz, $1H_{Ar}$), 6.95 (s, $1H_{Ar}$), 6.97 (d, J = 8Hz, $1H_{Ar}$). ^{13}C NMR (CD_3CN, ppm) δ: 21.65 (CH_3), 36.55 (CH_2), 121.96, 123.13, 125.30, 137.23, 139.24, 142.53. MS EI (70 eV) *m/z* (%): 136 (100, M^+), 121 (15, $M^+ - CH_3$), 91 (25, $M^+ - S - CH_3$). HRMS (EI) calcd. for (M^+) C_8H_8S: 136.0347; found: 136.0346.

7-Methyl-4*H*-benzo[d][1,3]oxathiin-2-one (3d)

Yield 60%. Colorless needles, mp 71 to 72 °C. ^1H NMR (CD_3CN, ppm) δ: 2.40 (s, 3H, CH_3), 5.37 (s, 2H, CH_2), 7.24 (d, J = 8Hz, $1H_{Ar}$), 7.25 (s, $1H_{Ar}$), 7.36 (d, J = 8Hz, $1H_{Ar}$). ^{13}C NMR (CD_3CN, ppm) δ: 20.69 (CH_3), 72.19 (CH_2), 126.59, 126.87, 127.20, 128.81, 130.95, 140.57, 166.89 (C=O). MS EI (70 eV) *m/z* (%): 180 (25, M^+), 136 (100, $M^+ - CO_2$), 121 (8, $M^+ - CO_2 - CH_3$). HRMS (EI) calcd. for (M^+) $C_9H_8O_2S$: 180.0245; found: 180.0246.

5-Methoxy-2*H*-benzo[b]thiete (1e)

Yield 84%. Colorless prisms, mp 27 to 28 °C. ^1H NMR (CD_3CN, ppm) δ: 3.79 (s, 3H, OCH_3), 4,41 (s, 2H, CH_2), 6.55 (d, J = 7Hz, $1H_{Ar}$), 6.61 (s, $1H_{Ar}$), 6.69 (d, J = 7Hz, $1H_{Ar}$). ^{13}C NMR (CD_3CN, ppm) δ: 37.07 (CH_2), 56.11 (OCH_3), 108.18, 111.68, 118.80, 132.35, 143.91, 161.70 (C5). MS EI (70 eV) *m/z* (%): 152 (100, M^+), 137 (5, $M^+ - CH_3$), 121 (10, $M^+ - OCH_3$), 107 (25, $M^+ - CH_2 - OCH_3$). HRMS (EI) calcd. for (M^+) C_8H_8OS: 152.0296; found: 152.0297.

7-Methoxy-4*H*-benzo[d][1,3]oxathiin-2-one (3e)

Yield 62%. Colorless needles, mp 76 to 77 °C. ^1H NMR (CD_3CN, ppm) δ: 3.74 (s, 3H, CH_3), 5.16 (s, 2H, CH_2), 6.73 (d, J = 7.5Hz, $1H_{Ar}$), 6.76 (s, $1H_{Ar}$), 7.18 (d, J = 7.5 Hz, $1H_{Ar}$). ^{13}C NMR (CD_3CN, ppm) δ: 56.43 (OCH_3), 72.57 (CH_2), 112.46, 114.26, 121.92, 128.99, 133.10, 161.44 (C5), 167.23 (C=O). MS EI (70 eV) *m/z* (%): 196 (25, M^+), 152 (100, $M^+ - CO_2$), 121 (10, $M^+ - CO_2 - OCH_3$). HRMS (EI) calcd. for (M^+) $C_9H_8O_3S$: 196.0194; found: 196.0197.

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