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Synthesis of 2-(trifluoromethyl)-1,2-dihydro-4*H*-thieno[2,3-*c*]chromen-4-ones and 2-(trifluoromethyl)-4*H*-thieno[2,3-*c*]chromen-4-ones from 2-trifluoromethylchromones and ethyl mercaptoacetate

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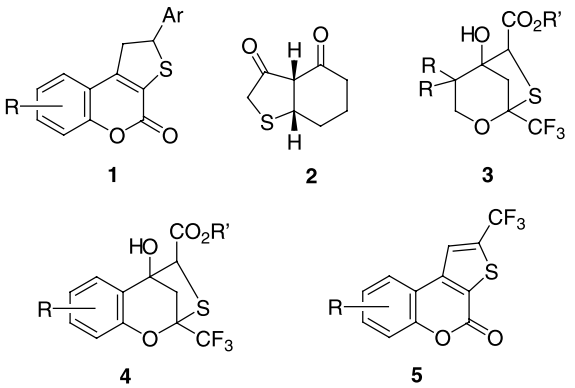
Abstract—The redox reaction of 2-trifluoromethylchromones with ethyl mercaptoacetate in the presence of triethylamine results in the formation of 1,2-dihydrothieno[2,3-*c*]chromen-4-ones and diethyl 3,4-dithiadipate in high yields. Oxidation of the first compounds with nitrogen dioxide gave 1,2-dihydrothieno[2,3-*c*]chromen-3,4-diones which were converted into thieno[2,3-*c*]chromen-4-ones.

1. Introduction

It is known[1,2] that the interaction of ethyl mercaptoacetate with α,β-unsaturated ketones proceeds via nucleophilic addition of the mercapto group to an activated C=C bond with further cyclization at the carbonyl group leading to the corresponding thiophene derivatives. A similar reaction of alkyl mercaptoacetates with esters of 3-methoxy-4,4,4-trifluorocrotonic,[3] α-fluoroalkyl acetic[4] and fluoroalkyl propiolic[5] acids gives alkyl 3-hydroxy-5-fluoroalkylthiophene-2-carboxylates, and with β-chloroenones[6] and α-fluoroalkyl ketones[4] alkyl 5-fluoroalkylthiophene-2-carboxylates are formed. *o*-Hydroxychalcones[7,8] can also participate in this reaction, but owing to *ortho*-hydroxyl group reaction is accompanied by tandem cyclization–dehydration to 2-aryl-1,2-dihydro-4*H*-thieno[2,3-*c*]chromen-4-ones (dihydrothienocoumarins) **1**. When the double bond is incorporated into the cycle, as in the case of cyclohex-2-enone,[9] the mode of interaction with methyl mercaptoacetate is changed and the initial product of a Michael addition undergoes a spontaneous cyclization with concomitant loss of methoxide to afford the diketone **2**, existing in the enolic form. At the same time we have recently[10] studied the reaction of 3,3-dialkyl-6-trifluoromethyl-2,3-dihydro-4-pyrones with methyl and ethyl mercaptoacetates and found that in this case, the reaction occurs with participation of both electrophilic centers of dihydropyrones without ring cleavage to give derivatives of 2-oxa-7-thiabicyclo[3.2.1]octane **3** (Scheme 1).



Scheme 1.

2. Results and discussion

In view of the unique biological properties displayed by many fluorinated heterocyclic compounds[11] and as an extension of our continuing synthetic studies concerning the reactivity of 2-polyfluoroalkylchromones,[12,13] we have started investigations of the possible use of 2-trifluoromethylchromones[14] in the reaction with ethyl mercaptoacetate. Taking into account the results of previous work[7,8,10] it might be expected that this reaction would proceed

Keywords: CF_3-containing chromones, coumarins, sulfur heterocycles; ethyl mercaptoacetate; redox reaction.

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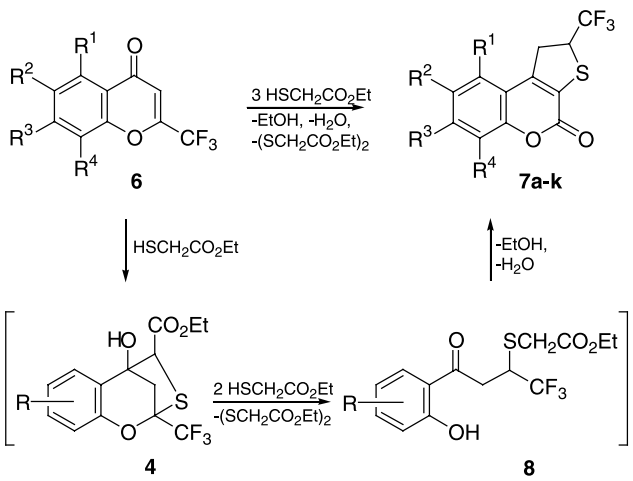


7a: $R^1 = R^2 = R^3 = R^4 = H$ (85%)
7b: $R^1 = R^3 = R^4 = H$, $R^2 = Me$ (79%)
7c: $R^1 = R^3 = R^4 = H$, $R^2 = MeO$ (93%)
7d: $R^1 = R^2 = R^4 = H$, $R^3 = MeO$ (91%)
7e: $R^1 = R^3 = R^4 = H$, $R^2 = NH_2$ (72%)
7f: $R^1 = R^3 = R^4 = H$, $R^2 = Cl$ (80%)
7g: $R^1 = R^3 = R^4 = H$, $R^2 = Br$ (83%)
7h: $R^1 = R^3 = H$, $R^2 = R^4 = Br$ (69%)
7i: $R^2 = R^4 = H$, $R^1 = R^3 = Me$ (89%)
7j: $R^1 = R^2 = H$, $R^3 + R^4 =$ benzo (74%)
7k: $R^1 + R^2 =$ benzo, $R^3 = R^4 = H$ (66%)

Scheme 2.

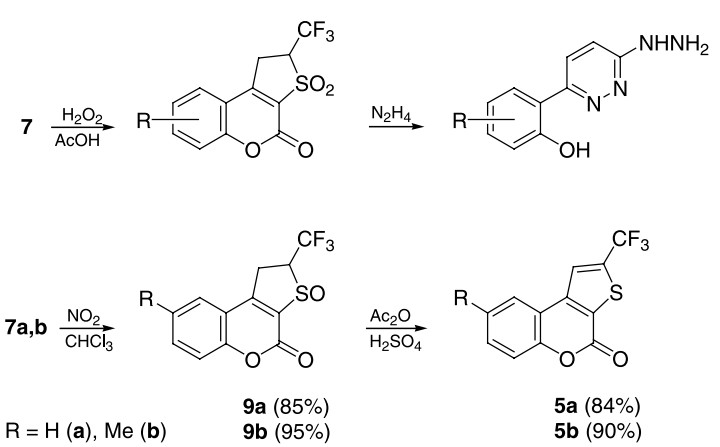
either without opening of the pyrone ring to give benzo derivatives of 2-oxa-7-thiabicyclo[3.2.1]octane **4** or with ring opening. In the latter case, the reaction can be accompanied by cyclization and dehydration stages[7,8] to yield thieno[2,3-*c*]coumarins **5** (Scheme 1).

Here we describe our findings on the successful application of this reaction to the preparation of trifluoromethyl-containing coumarin derivatives (preliminary communication see Ref. 15). We found that the interaction of 2-trifluoromethylchromones **6** with ethyl mercaptoacetate in a molar ratio of 1:3 at 80°C in the presence of Et_3N as a catalyst afforded dihydrothienocoumarins **7a–k** in 66–93% yields. Also diethyl 3,4-dithiadipate was isolated and identified as the second product of this transformation. These products can be viewed as resulting from a redox reaction between chromones **6** and ethyl mercaptoacetate, and no trace of an expected compounds **4** and **5** was observed (Scheme 2).

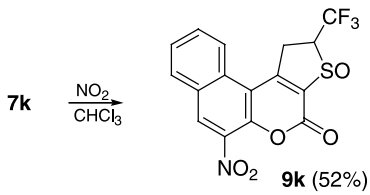
The mechanism for the redox formation of coumarins **7** is not obvious, but it is most likely that, as in the cases with 3,3-dialkyl-6-trifluoromethyl-2,3-dihydro-4-pyrones[10] and 7-polyfluoroalkylnorkhellins,[16] the reaction initially gives benzo derivative of 2-oxa-7-thiabicyclo[3.2.1]octane **4**, which undergoes reductive ring-opening to ester **8** under the action of ethyl mercaptoacetate. The latter compound is oxidized to diethyl 3,4-dithiadipate and further two intramolecular cyclizations of the intermediate ester **8** give dihydrothienocoumarins **7** (Scheme 2).

The substitutions on the phenyl ring did not effect the synthetic results, but this reaction is typical only for 2-trifluoromethylchromones and does not proceed with 2-difluoromethyl-, 2-(1,1,2,2-tetrafluoroethyl)-, 2-trichloromethyl- and 2-methylchromones. The structures of the coumarins **7** compare well with the results of elemental analysis, ^1H, ^{13}C, ^{19}F NMR and IR spectroscopy and mass spectrometry. Furthermore, an X-ray diffraction analysis of **7b** was performed, proving the regiochemistry of the reaction.[15] The ^1H NMR spectra of these compounds showed signals for the aromatic protons and a characteristic ABX-system ranging between 3.6–4.4 and 4.3–5.2 ppm for the aliphatic protons of the CH_2 and CH groups, respectively; the coupling constants were $^2J_{AB}$=17.7–19.2 Hz, $^3J_{AX}$=10.3–12.3 Hz, and $^3J_{BX}$=2.6–4.5 Hz.

The ready accessibility of dihydrothienocoumarins **7** have made them useful substrates for constructing highly functionalized biologically and medicinally important products. Selective sulfur oxidation of these compounds to sulfoxides or to sulfones is the more attractive route to increase their reactivity. Indeed, we have recently reported[17] that the oxidation of compounds **7** in glacial acetic acid containing an excess of aqueous hydrogen peroxide (30%) selectively gives sulfones, 2-(trifluoromethyl)-1,2-dihydrothieno[2,3-*c*]chromen-3,3,4-triones, which are transformed into 3-hydrazino-6-(2-hydroxyaryl)-pyridazines under the action of hydrazine hydrate in ethanol. This reaction is undoubtedly of interest since



Scheme 3.



Scheme 4.

several derivatives of 3-hydrazinopyridazine exhibit different types of biological activity as chemotherapeutics, anti-inflammatory agents, CNS depressants and stimulants, and anti-hypertensives[18] (Scheme 3).

In this work, we were unable to selectively convert dihydrothienocoumarins **7** to the corresponding sulfoxides **9** using a stoichiometric amount of the H_2O_2–AcOH system and the use of well-known conventional oxidants such as $Na_2Cr_2O_7$–H_2SO_4 and ClO_2–$CHCl_3$, lead to complex reaction mixtures. However, as representative examples, we converted sulfides **7a**,**b** to sulfoxides **9a**,**b** in chloroform with an excess of NO_2 at room temperature over four days in high yields and with quite complete chemoselectivity (Scheme 3). The ^{1}H NMR spectra of **9a**,**b** showed a characteristic AMX-system for the aliphatic protons of the CH_2 and CH groups with $^2J_{AM}$=18.7 Hz, $^3J_{AX}$=8.9 Hz, and $^3J_{MX}$=3.6–3.7 Hz. It is worth mentioning that coumarin **7k** gave nitrosulfoxide **9k** under the same conditions (Scheme 4).

Note that sulfoxides **9a**,**b**, in contrast to corresponding sulfones did not react with hydrazine hydrate, but with **9a**,**b** in hand we were able to prepare thieno[2,3-*c*]coumarins **5a**,**b** using the Pummerer rearrangement followed by aromatization. Thus, heating for a short time (1–2 min) of sulfoxides **9a**,**b** with acetic anhydride in the presence of a catalytic amounts of H_2SO_4 cleanly afforded thieno[2,3-*c*] coumarins **5a**,**b** in 84–90% yields. The ^{1}H NMR spectrum of **5a** in $CDCl_3$ displayed no signals for CH_2 and CH protons; however, a quartet at δ 7.96 with $^4J_{H,F}$=0.9 Hz assigned to the thiophene proton was observed.

In conclusion, the reaction of 2-trifluoromethylchromones with ethyl mercaptoacetate provides a simple and convenient one-pot process from the readily available starting materials to CF_3-containing 1,2-dihydrothieno[2,3-*c*]chromen-4-ones **7** in high yields, which are expected to be biologically active[19] and can be used as optical brightening agents, dispersed fluorescent and laser dyes.[20] Moreover, these compounds are useful substrates for constructing biologically and medicinally important products.

3. Experimental

3.1. General

^{1}H NMR spectra were recorded on a Bruker WM-250 and Bruker DRX-400 spectrometers operating at 250.13 or at 400.13 MHz in $CDCl_3$ or DMSO-d_6 solutions with TMS as the internal standard. ^{19}F and ^{13}C NMR spectra were recorded on a Bruker DPS-200 spectrometer operating at 188.3 and 50.3 MHz, respectively. IR spectra were measured on an IKS-29 instrument as suspensions in vaseline oil. Mass spectra (electron impact, 70 eV) were carried out on a MAT 8200 spectrometer. Elementary analyses were performed at the Microanalysis Services of the Institute of Organic Synthesis, Ural Branch, Russian Academy of Sciences. Melting points are uncorrected. The starting chromones **6** were prepared by condensation of the appropriate 2-hydroxyacetophenones with ethyl trifluoroacetate according to described procedure.[21] Assignment of the signals in ^{13}C NMR spectra was performed on the basis of a gradient selected 2D HMBC spectrum[22] and of data in Ref. 23.

3.1.1. Dihydrothienocoumarins 7a–k; general procedure. A mixture of chromone **6** (4.7 mmol), ethyl mercaptoacetate (2.0 g, 17 mmol) and Et_3N (0.5 ml) without solvent was heated at 80°C for 12 h. After cooling, the reaction mixture was diluted with 5 ml of ethanol and the crystalline material was isolated by filtration and washed with ethanol to give **7** as a colourless or light yellow crystals. After recrystallization from ethanol, the melting point did not change.

The filtrate obtained after removal of **7a** was distilled in vacuo to give diethyl 3,4-dithiadipate, yield 43%, bp 135–140°C (5 mmHg), n_D^{20}=1.4962 (lit.,[24] bp 112–116°C/0.3 mmHg, n_D^{25} 1.4950); ν_{max} (neat) 1720 (C=O) cm^{-1}; δ_H (400 MHz, $CDCl_3$) 1.30 (3H, t, *J*=7.1 Hz, Me), 3.58 (2H, s, CH_2S), 4.22 (2H, q, *J*=7.1 Hz, CH_2O).

3.1.2. 2-(Trifluoromethyl)-1,2-dihydro-4*H*-thieno[2,3-*c*]chromen-4-one (7a). Yield 85%, mp 146–147°C; (Found: C, 52.84; H, 2.64. $C_{12}H_7F_3O_2S$ requires C, 52.94; H, 2.59%); ν_{max} 1720 (C=O), 1610, 1560w (C=C, arom.) cm^{-1}; δ_H (250.1 MHz, $CDCl_3$) 3.66–3.85 (2H, AB-part of ABX-system, δ_A=3.78, δ_B=3.73, $^2J_{AB}$=18.3 Hz, $^3J_{AX}$=10.3 Hz, $^3J_{BX}$=4.5 Hz, CH_2), 4.37–4.53 (1H, m, CH), 7.28–7.40 (3H, m, H^6, H^8, H^9), 7.51 (1H, ddd, $J_{H7,H6}$=8.6 Hz, $J_{H7,H8}$=6.9 Hz, $J_{H7,H9}$=2.0 Hz, H^7); δ_C (50.3 MHz, $CDCl_3$) 35.72 (q, $^3J_{C,F}$=2.3 Hz, CH_2), 47.80 (q, $^2J_{C,F}$=31.6 Hz, CH), 125.54 (q, $^1J_{C,F}$=277.8 Hz, CF_3), 144.97 (=C–S), 152.95 (=C–O), 156.08 (C=O), 116.92, 117.43, 123.92, 124.93, 126.34, 130.86; δ_F (188.3 MHz, $CDCl_3$, $CFCl_3$) −75.28 (d, $^3J_{F,H}$=8.6 Hz, CF_3); MS (70 eV, 200°C), *m*/*z* (I_{rel} (%)): 272 [M]$^+$ (100), 253 [M−F]$^+$ (3), 244 [M−CO]$^+$ (3), 203 [M−CF_3]$^+$ (23), 175 [M−CO–CF_3]$^+$ (3), 159 [M−CO_2–CF_3]$^+$ (45), 115 [HS=CH–CF_3]$^+$ (41), 69 [CF_3]$^+$ (4), 45 [HC≡S]$^+$ (5), 28 [CO]$^+$ (15).

3.1.3. 8-Methyl-2-(trifluoromethyl)-1,2-dihydro-4*H*-thieno[2,3-*c*]chromen-4-one (7b). Yield 79%, mp 181–182°C; (Found: C, 54.36; H, 3.15. $C_{13}H_9F_3O_2S$ requires C, 54.54; H, 3.17%); ν_{max} 1710 (C=O), 1610, 1570 (C=C, arom.) cm^{-1}; δ_H (250.1 MHz, $CDCl_3$) 2.42 (3H, s, Me), 3.65–3.84 (2H, *AB*X, δ_A=3.76, δ_B=3.72, $^2J_{AB}$=18.4 Hz, $^3J_{AX}$=11.0 Hz, $^3J_{BX}$=3.8 Hz, CH_2), 4.36–4.52 (1H, m, CH), 7.13 (1H, br s, H^9), 7.25 (1H, d, ^oJ=8.3 Hz, H^6), 7.31 (1H, dd, ^oJ=8.3 Hz, ^mJ=1.7 Hz, H^7); δ_C (90.6 MHz, $CDCl_3$) 20.85 (Me), 35.75 (CH_2), 47.80 (q, $^2J_{C,F}$=31.7 Hz, CH), 125.58 (q, $^1J_{C,F}$=277.9 Hz, CF_3), 144.89 (=C–S), 151.20 (=C–O), 156.30 (C=O), 116.68, 117.21, 123.75, 126.22, 131.86, 134.76; δ_F (188.3 MHz, $CDCl_3$, $CFCl_3$) −75.30 (d, $^3J_{F,H}$=8.6 Hz,

CF_3); MS (70 eV, 200°C), *m/z* (I_{rel} (%)): 286 $[M]^+$ (100), 267 $[M-F]^+$ (2), 258 $[M-CO]^+$ (4), 217 $[M-CF_3]^+$ (16), 189 $[M-CO-CF_3]^+$ (4), 173 $[M-CO_2-CF_3]^+$ (27), 115 $[HS{=}CH-CF_3]^+$ (7), 69 $[CF_3]^+$ (3), 45 $[HC{\equiv}S]^+$ (4), 28 $[CO]^+$ (13).

3.1.4. 8-Methoxy-2-(trifluoromethyl)-1,2-dihydro-4*H*-thieno[2,3-*c*]chromen-4-one (7c). Yield 93%, mp 185–186°C; (Found: C, 51.60; H, 2.97. $C_{13}H_9F_3O_3S$ requires C, 51.66; H, 3.00%); ν_{max} 1710 (C=O), 1620, 1570 (C=C, arom.) cm^{-1}; δ_H (250.1 MHz, $CDCl_3$) 3.63–3.83 (2H, *AB*X, δ_A=3.76, δ_B=3.70, $^2J_{AB}$=18.3 Hz, $^3J_{AX}$=10.7 Hz, $^3J_{BX}$=4.5 Hz, CH_2), 3.86 (3H, s, MeO), 4.37–4.52 (1H, m, CH), 6.75 (1H, d, ^mJ=2.8 Hz, H^9), 7.06 (1H, dd, ^oJ=9.1 Hz, ^mJ=2.8 Hz, H^7), 7.30 (1H, d, ^oJ=9.1 Hz, H^6); δ_C (90.6 MHz, DMSO-d_6+$CDCl_3$) 35.32 (CH_2), 46.89 (q, $^2J_{C,F}$=31.2 Hz, CH), 55.32 (MeO), 125.32 (q, $^1J_{C,F}$=277.7 Hz, CF_3), 106.41, 117.05, 117.33, 117.91, 125.40, 145.20, 146.67, 155.47, 155.76; δ_F (188.3 MHz, DMSO-d_6+$CDCl_3$, $CFCl_3$) −74.90 (d, $^3J_{F,H}$=8.6 Hz, CF_3); MS (70 eV, 200°C), *m/z* (I_{rel} (%)): 302 $[M]^+$ (87), 283 $[M-F]^+$ (2), 274 $[M-CO]^+$ (22), 272 $[M-CH_2O]^+$ (100), 259 $[M-CO-CH_3]^+$ (8), 233 $[M-CF_3]^+$ (23), 205 $[M-CO-CF_3]^+$ (5), 203 $[M-CH_2O-CF_3]^+$ (16), 189 $[M-CO_2-CF_3]^+$ (8), 159 $[M-CH_2O-CO_2-CF_3]^+$ (35), 115 $[HS{=}CH-CF_3]^+$ (29), 69 $[CF_3]^+$ (6), 45 $[HC{\equiv}S]^+$ (4), 28 $[CO]^+$ (46).

3.1.5. 7-Methoxy-2-(trifluoromethyl)-1,2-dihydro-4*H*-thieno[2,3-*c*]chromen-4-one (7d). Yield 91%, mp 172–173°C; (Found: C, 51.62; H, 2.93. $C_{13}H_9F_3O_3S$ requires C, 51.66; H, 3.00%); ν_{max} 1710 (C=O), 1620, 1605, 1550 (C=C, arom.) cm^{-1}; δ_H (250.1 MHz, $CDCl_3$) 3.61–3.81 (2H, *AB*X, δ_A=3.73, δ_B=3.67, $^2J_{AB}$=18.3 Hz, $^3J_{AX}$=10.4 Hz, $^3J_{BX}$=4.2 Hz, CH_2), 3.87 (3H, s, MeO), 4.34–4.50 (1H, m, CH), 6.86 (1H, br s, H^6), 6.88 (1H, dd, ^oJ=8.1 Hz, ^mJ=2.4 Hz, H^8), 7.25 (1H, dd, ^oJ=8.1 Hz, ^pJ=0.7 Hz, H^9).

3.1.6. 8-Amino-2-(trifluoromethyl)-1,2-dihydro-4*H*-thieno[2,3-*c*]chromen-4-one (7e). Yield 72%, mp 202–204°C; (Found: C, 50.06; H, 2.67; N, 4.90. $C_{12}H_8F_3NO_2S$ requires C, 50.18; H, 2.81; N, 4.88%); ν_{max} 3390 (NH_2), 1710 (C=O), 1630, 1570 (C=C, arom.) cm^{-1}; δ_H (400.1 MHz, DMSO-d_6) 3.66 (1H, dd, ^2J=18.7 Hz, ^3J=3.5 Hz, C*H*H), 3.93 (1H, dd, ^2J=18.7 Hz, ^3J=10.6 Hz, CH*H*), 5.06 (1H, quint d, $^3J_{H,H}$=$^3J_{H,F}$=9.0 Hz, $^3J_{H,H}$=3.4 Hz, CH), 5.30 (2H, s, NH_2), 6.68 (1H, d, ^mJ=2.6 Hz, H^9), 6.84 (1H, dd, ^oJ=8.9 Hz, ^mJ=2.6 Hz, H^7), 7.18 (1H, d, ^oJ=8.9 Hz, H^6).

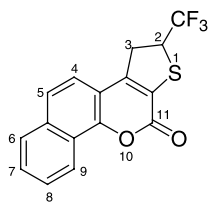
3.1.7. 8-Chloro-2-(trifluoromethyl)-1,2-dihydro-4*H*-thieno[2,3-*c*]chromen-4-one (7f). Yield 80%, mp 181–182°C; (Found: C, 47.15; H, 1.79. $C_{12}H_6ClF_3O_2S$ requires C, 47.00; H, 1.97%); ν_{max} 1710 (C=O), 1610, 1565 (C=C, arom.) cm^{-1}; δ_H (400.1 MHz, $CDCl_3$) 3.67–3.81 (2H, *AB*X, δ_A=3.76, δ_B=3.70, $^2J_{AB}$=18.2 Hz, $^3J_{AX}$=10.9 Hz, $^3J_{BX}$=4.3 Hz, CH_2), 4.41–4.51 (1H, m, CH), 7.32 (1H, d, ^oJ=8.9 Hz, H^6), 7.33 (1H, d, ^mJ=2.4 Hz, H^9), 7.45 (1H, dd, ^oJ=8.9 Hz, ^mJ=2.4 Hz, H^7); δ_C (90.6 MHz, DMSO-d_6) 35.43 (CH_2), 46.83 (q, $^2J_{C,F}$=30.5 Hz, CH), 126.10 (q, $^1J_{C,F}$=277.5 Hz, CF_3), 145.99 (=C–S), 151.04 (=C–O), 155.25 (C=O), 118.24, 118.54, 124.59, 125.96, 128.93, 130.58; δ_F (188.3 MHz, DMSO-d_6, $CFCl_3$) −74.40 (d, $^3J_{F,H}$=8.6 Hz, CF_3); MS (70 eV, 200°C), *m/z* (I_{rel} (%)): 306 $[M]^+$ (100), 278 $[M-CO]^+$ (4), 237 $[M-CF_3]^+$ (20), 193 $[M-CO_2-CF_3]^+$ (18), 158 $[M-CO_2-CF_3-Cl]^+$ (15), 69 $[CF_3]^+$ (6), 45 $[HC{\equiv}S]^+$ (4), 28 $[CO]^+$ (15).

3.1.8. 8-Bromo-2-(trifluoromethyl)-1,2-dihydro-4*H*-thieno[2,3-*c*]chromen-4-one (7g). Yield 83%, mp 196–197°C; (Found: C, 41.14; H, 1.69. $C_{12}H_6BrF_3O_2S$ requires C, 41.05; H, 1.72%); ν_{max} 1710 (C=O), 1600, 1550 (C=C, arom.) cm^{-1}; δ_H (250.1 MHz, $CDCl_3$) 3.63–3.83 (2H, *AB*X, δ_A=3.75, δ_B=3.70, $^2J_{AB}$=18.3 Hz, $^3J_{AX}$=11.1 Hz, $^3J_{BX}$=3.8 Hz, CH_2), 4.38–4.54 (1H, m, CH), 7.26 (1H, d, ^oJ=8.8 Hz, H^6), 7.47 (1H, d, ^mJ=2.0 Hz, H^9), 7.58 (1H, dd, ^oJ=8.8 Hz, ^mJ=2.0 Hz, H^7).

3.1.9. 6,8-Dibromo-2-(trifluoromethyl)-1,2-dihydro-4*H*-thieno[2,3-*c*]chromen-4-one (7h). Yield 69%, mp 194–196°C; (Found: C, 33.56; H, 0.86. $C_{12}H_5Br_2F_3O_2S$ requires C, 33.52; H, 1.17%); ν_{max} 1725 (C=O), 1615, 1545 (C=C, arom.) cm^{-1}; δ_H (400.1 MHz, DMSO-d_6) 3.89–4.03 (2H, *AB*X, δ_A=3.99, δ_B=3.94, $^2J_{AB}$=19.2 Hz, $^3J_{AX}$=3.4 Hz, $^3J_{BX}$=10.9 Hz, CH_2), 5.11–5.21 (1H, m, CH), 7.99 (1H, d, ^mJ=2.2 Hz, H^9), 8.12 (1H, d, ^mJ=2.2 Hz, H^7).

3.1.10. 7,9-Dimethyl-2-(trifluoromethyl)-1,2-dihydro-4*H*-thieno[2,3-*c*]chromen-4-one (7i). Yield 89%, mp 165–166°C; (Found: C, 56.26; H, 3.74. $C_{14}H_{11}F_3O_2S$ requires C, 56.00; H, 3.69%); ν_{max} 1720 (C=O), 1620, 1600 (C=C, arom.) cm^{-1}; δ_H (250.1 MHz, $CDCl_3$) 2.37 (3H, s, Me^7), 2.61 (3H, s, Me^9), 3.89–4.04 (2H, *AB*X, δ_A=4.01, δ_B=3.95, $^2J_{AB}$=18.2 Hz, $^3J_{AX}$=11.3 Hz, $^3J_{BX}$=3.6 Hz, CH_2), 4.29–4.45 (1H, m, CH), 6.90 (1H, s, H^8), 7.02 (1H, s, H^6); δ_C (90.6 MHz, $CDCl_3$) 21.28 (Me), 22.83 (Me), 39.85 (CH_2), 47.36 (q, $^2J_{C,F}$=31.2 Hz, CH), 125.64 (q, $^1J_{C,F}$=278.1 Hz, CF_3), 144.82 (=C–S), 154.21 (=C–O), 156.27 (C=O), 115.07, 115.92, 125.68, 129.25, 133.86, 141.25; δ_F (188.3 MHz, $CDCl_3$, $CFCl_3$) −75.42 (d, $^3J_{F,H}$=8.6 Hz, CF_3); MS (70 eV, 200°C), *m/z* (I_{rel} (%)): 300 $[M]^+$ (100), 281 $[M-F]^+$ (3), 272 $[M-CO]^+$ (5), 231 $[M-CF_3]^+$ (24), 203 $[M-CO-CF_3]^+$ (13), 187 $[M-CO_2-CF_3]^+$ (58), 172 $[M-CO_2-CF_3-CH_3]^+$ (20), 115 $[HS{=}CH-CF_3]^+$ (15), 69 $[CF_3]^+$ (5), 45 $[HC{\equiv}S]^+$ (5), 28 $[CO]^+$ (9).

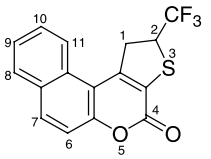
3.1.11. 2-(Trifluoromethyl)-2,3-dihydro-11*H*-benzo[*h*]thieno[2,3-*c*]chromen-11-one (7j).



Yield 74%, mp 212–213°C; (Found: C, 59.93; H, 2.87. $C_{16}H_9F_3O_2S$ requires C, 59.63; H, 2.81%); ν_{max} 1715 (C=O), 1630w, 1600, 1560w, 1510w (C=C, arom.) cm^{-1}; δ_H (250.1 MHz, $CDCl_3$) 3.74–3.89 (2H, *AB*X, δ_A=3.83, δ_B=3.78, $^2J_{AB}$=18.4 Hz, $^3J_{AX}$=2.7 Hz, $^3J_{BX}$=12.3 Hz, CH_2), 4.39–4.55 (1H, m, CH), 7.31 (1H, d, ^oJ=8.5 Hz, H^5), 7.58–7.65 (2H, m, H^7, H^8), 7.68 (1H, d, ^oJ=8.5 Hz, H^4), 7.82–7.86 (1H, m, H^6), 8.45–8.49 (1H, m, H^9); δ_C

(50.3 MHz, $CDCl_3$) 36.04 (q, $^3J_{C,F}$=2.0 Hz, CH_2), 47.98 (q, $^2J_{C,F}$=31.7 Hz, CH), 125.61 (q, $^1J_{C,F}$=278.2 Hz, CF_3), 146.05 (=C–S), 149.95 (=C–O), 156.12 (C=O), 113.00, 119.89, 122.24, 122.98, 125.14, 125.65, 127.58, 127.87, 128.49, 134.12; δ_F (188.3 MHz, $CDCl_3$, $CFCl_3$) −75.21 (d, $^3J_{F,H}$=8.6 Hz, CF_3); MS (70 eV, 200°C), *m/z* (I_{rel} (%)): 322 $[M]^+$ (74), 294 $[M-CO]^+$ (11), 253 $[M-CF_3]^+$ (5), 225 $[M-CO-CF_3]^+$ (5), 209 $[M-CO_2-CF_3]^+$ (9), 115 $[HS{=}CH-CF_3]^+$ (18), 86 (100), 69 $[CF_3]^+$ (9), 45 $[HC{\equiv}S]^+$ (6), 28 $[CO]^+$ (66).

3.1.12. 2-(Trifluoromethyl)-1,2-dihydro-4*H*-benzo[*f*]thieno[2,3-*c*]chromen-4-one (7k).



Yield 66%, mp 228–229°C; (Found: C, 59.37; H, 2.88. $C_{16}H_9F_3O_2S$ requires C, 59.63; H, 2.81%); ν_{max} 1720 (C=O), 1620w, 1600w, 1580w, 1540w, 1515w (C=C, arom.) cm^{-1}; δ_H (250.1 MHz, $CDCl_3$) 4.23–4.38 (2H, *AB*X, δ_A=4.31, δ_B=4.26, $^2J_{AB}$=17.7 Hz, $^3J_{AX}$=2.6 Hz, $^3J_{BX}$=11.9 Hz, CH_2), 4.43–4.59 (1H, m, CH), 7.47 (1H, d, ^oJ=9.1 Hz, H^6), 7.58 (1H, t, ^oJ=7.5 Hz, H^9), 7.68 (1H, td, ^oJ=7.7 Hz, ^mJ=1.2 Hz, H^{10}), 7.92 (2H, d, ^oJ=8.7 Hz, H^7, H^8), 8.24 (1H, d, ^oJ=8.5 Hz, H^{11}); δ_C (50.3 MHz, $CDCl_3$) 40.81 (q, $^3J_{C,F}$=2.0 Hz, CH_2), 47.75 (q, $^2J_{C,F}$=31.4 Hz, CH), 125.60 (q, $^1J_{C,F}$=278.2 Hz, CF_3), 144.63 (=C–S), 153.31 (=C–O), 156.04 (C=O), 113.08, 117.44, 123.80, 125.94, 127.39, 128.11, 128.61, 129.73, 131.22, 132.45; δ_F (188.3 MHz, $CDCl_3$, $CFCl_3$) −75.33 (d, $^3J_{F,H}$=8.6 Hz, CF_3); MS (70 eV, 200°C), *m/z* (I_{rel} (%)): 322 $[M]^+$ (100), 294 $[M-CO]^+$ (5), 253 $[M-CF_3]^+$ (42), 225 $[M-CO-CF_3]^+$ (6), 209 $[M-CO_2-CF_3]^+$ (7), 115 $[HS{=}CH-CF_3]^+$ (5), 86 (64), 69 $[CF_3]^+$ (8), 45 $[HC{\equiv}S]^+$ (3), 28 $[CO]^+$ (29).

3.2. Sulfoxides 9a,b,k; general procedure

A solution of dihydrothienocoumarin **7** (3.0 mmol) in chloroform (10 ml) saturated by NO_2 was kept at room temperature for four days. After evaporation of $CHCl_3$ the residue was diluted with water (20 ml) and the crystalline materials was isolated by filtration, washed with water (100 ml), dried, and recrystallized from toluene.

3.2.1. 2-(Trifluoromethyl)-1,2-dihydro-3λ⁴-thieno[2,3-*c*]chromen-3,4-dione (9a).

Yield 85%, mp 208–209°C; (Found: C, 50.18; H, 2.32. $C_{12}H_7F_3O_3S$ requires C, 50.00; H, 2.45%); ν_{max} 1725 (C=O), 1620, 1570 (C=C, arom.) cm^{-1}; δ_H (400.1 MHz, $CDCl_3$) 3.67 (1H, dd, ^2J=18.7 Hz, ^3J=3.7 Hz, C*H*H), 4.10 (1H, quint d, $^3J_{H,H}$=$^3J_{H,F}$=9.2 Hz, $^3J_{H,H}$=3.7 Hz, CH), 4.24 (1H, dd, ^2J=18.7 Hz, ^3J=8.9 Hz, CH*H*), 7.45 (1H, ddd, ^oJ=7.4, 8.0 Hz, ^mJ=1.0 Hz, H^8), 7.47 (1H, d, ^oJ=8.5 Hz, H^6), 7.63 (1H, dd, ^oJ=7.9 Hz, ^mJ=1.5 Hz, H^9), 7.76 (1H, ddd, ^oJ=8.6, 7.4 Hz, ^mJ=1.6 Hz, H^7).

3.2.2. 8-Methyl-2-(trifluoromethyl)-1,2-dihydro-3λ⁴-thieno[2,3-*c*]chromen-3,4-dione (9b).

Yield 95%, mp 199–200°C; (Found: C, 51.57; H, 2.85. $C_{13}H_9F_3O_3S$ requires C, 51.66; H, 3.00%); ν_{max} 1710 (C=O), 1620, 1565 (C=C, arom.) cm^{-1}; δ_H (400.1 MHz, $CDCl_3$) 2.47 (3H, s, Me), 3.65 (1H, dd, ^2J=18.7 Hz, ^3J=3.6 Hz, C*H*H), 4.08 (1H, quint d, $^3J_{H,H}$=$^3J_{H,F}$=9.2 Hz, $^3J_{H,H}$=3.6 Hz, CH), 4.21 (1H, dd, ^2J=18.7 Hz, ^3J=8.9 Hz, CH*H*), 7.36 (1H, d, ^oJ=8.5 Hz, H^6), 7.39 (1H, d, ^mJ=0.9 Hz, H^9), 7.55 (1H, dd, ^oJ=8.5 Hz, ^mJ=1.9 Hz, H^7).

3.2.3. 6-Nitro-2-(trifluoromethyl)-1,2-dihydro-3λ⁴-benzo[*f*]thieno[2,3-*c*]chromen-3,4-dione (9k).

Yield 52%, mp 210–212°C; (Found: C, 50.04; H, 2.10; N, 3.32. $C_{16}H_8F_3NO_5S$ requires C, 50.14; H, 2.10; N, 3.65%); ν_{max} 1725 (C=O), 1620, 1580, 1515 (C=C, arom.), 1545 (NO_2) cm^{-1}; δ_H (400.1 MHz, DMSO-d_6) 4.34 (1H, m, C*H*H), 4.93 (2H, m, CH*H*, CH), 7.90 (1H, ddd, ^oJ=8.2, 7.0 Hz, ^mJ=0.9 Hz, H^9 or H^{10}), 7.99 (1H, ddd, ^oJ=8.5, 7.0 Hz, ^mJ=1.4 Hz, H^{10} or H^9), 8.18 (1H, dd, ^oJ=8.5 Hz, ^mJ=1.2 Hz, H^8), 8.51 (1H, s, H^7), 8.71 (1H, d, ^oJ=8.7 Hz, H^{11}).

3.3. Thienocoumarins 5a,b; general procedure

A mixture of sulfoxide **9** (3.0 mmol), Ac_2O (3 ml) and 1 drop of conc. H_2SO_4 was refluxed for 1–2 min, the reaction was cooled, and the solid residue was isolated by filtration, washed with AcOH (100 ml), and dried.

3.3.1. 2-(Trifluoromethyl)-4*H*-thieno[2,3-*c*]chromen-4-one (5a).

Yield 84%, mp 169–170°C; (Found: C, 53.23; H, 1.83. $C_{12}H_5F_3O_2S$ requires C, 53.34; H, 1.87%); ν_{max} 3105 (=CH), 1725 (C=O), 1625, 1605w, 1560w (C=C, arom.) cm^{-1}; δ_H (250 MHz, $CDCl_3$) 7.39 (1H, ddd, ^oJ=7.8, 7.2 Hz, ^mJ=1.2, H^8), 7.47 (1H, dd, ^oJ=8.4 Hz, ^mJ=1.0 Hz, H^6), 7.56 (1H, ddd, ^oJ=8.4, 7.2 Hz, ^mJ=1.6 Hz, H^7), 7.83 (1H, dd, ^oJ=7.8 Hz, ^mJ=1.2 Hz, H^9), 7.96 (1H, q, $^4J_{H,F}$=0.9 Hz, H^1).

3.3.2. 8-Methyl-2-(trifluoromethyl)-4*H*-thieno[2,3-*c*]chromen-4-one (5b).

Yield 90%, mp 247–248°C; (Found: C, 54.84; H, 2.41. $C_{13}H_7F_3O_2S$ requires C, 54.93; H, 2.48%); ν_{max} 3135, 3105 (=CH), 1725 (C=O), 1620w, 1590w, 1555w (C=C, arom.) cm^{-1}; δ_H (400 MHz, DMSO-d_6) 2.43 (3H, s, Me), 7.44–7.49 (2H, m, H^6, H^7), 8.13 (1H, dq, ^mJ=2.1 Hz, $^4J_{H,Me}$=0.6 Hz, H^9), 8.80 (1H, q, $^4J_{H,F}$=1.0 Hz, H^1).

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