Unexpected conversion of 4-oxo-4*H*-chromene-2-carboxylic acid to 2-(1,3-benzothiazol-2-yl)-4*H*-chromen-4-one and spiro[1,4-benzothiazine-2,2'-chromene]-3,4'(3'*H*,4*H*)-dione

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SUPPLEMENTARY INFORMATION

Experimental

Reagents and general conditions

Chromone-2-carboxylic acid, 2-aminothiophenol, phosphorus(V) oxychloride, benzotriazol-1-yloxy)tripyrrolidinophosphonium hexafluorophosphate (PyBOP), N,N-diisopropylethylamine (DIPEA), dimethylformamide (DMF) and its derivatives were purchased from Sigma-Aldrich Química S.A. (Sintra, Portugal). All other reagents and solvents were pro analysis grade and were acquired from Merck (Lisbon, Portugal) and used without additional purification.

Thin-layer chromatography (TLC) was carried out on precoated silica gel 60 F254 (Merck) with layer thickness of 0.2 mm. For analytical control the following systems were used: ethyl acetate/petroleum ether, ethyl acetate/methanol, chloroform/methanol in several proportions. The spots were visualized under UV detection (254 and 366 nm) and iodine vapour. Column chromatography was performed using silica gel 60 0.2-0.5 or 0.040-0.063 mm (Merck).

NMR data

^{1}H and ^{13}C NMR spectra of samples, approximately 10% solutions in CDCl$_3$, were recorded at room temperature in 5mm outside diameter (o.d.) tubes. Tetramethylsilane (TMS) was used as internal standard, chemical shifts are expressed in ppm (δ) and J in Hz. One-dimensional ^{13}C NMR was recorded on a Bruker AMX 400 NMR spectrometer operating at 101.00 MHz preparation COSY and HSQC spectra were recorded on a Bruker AMX 400 spectrometer using pulse sequence that allowed gradient selection (Bruker programs INV4GS).
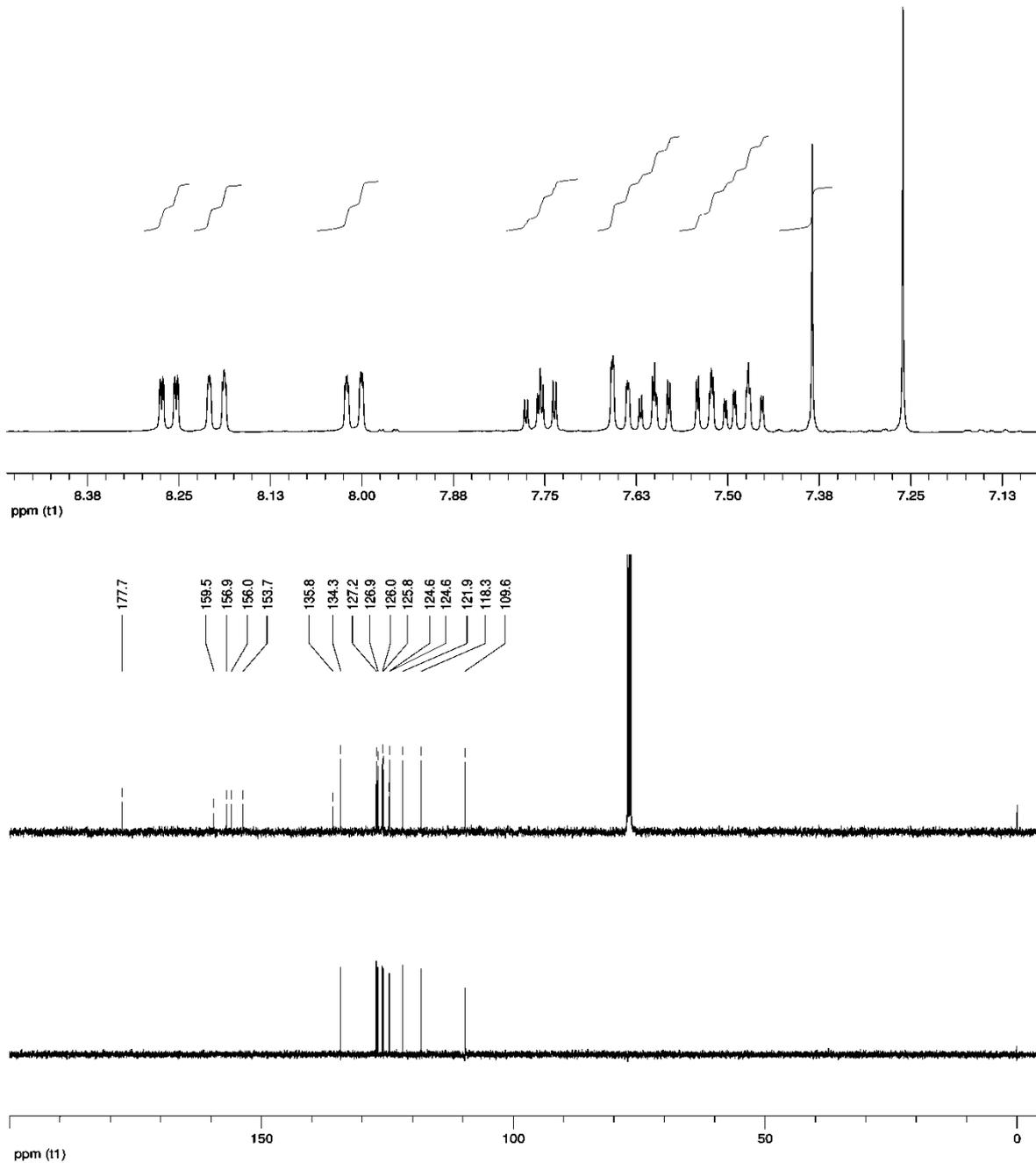
Figure **S1**. ^{1}H, ^{13}C and DEPT NMR spectra of 2-(benzo[*d*]thiazol-2-yl)-4*H*-chromen-4-one (**2**)
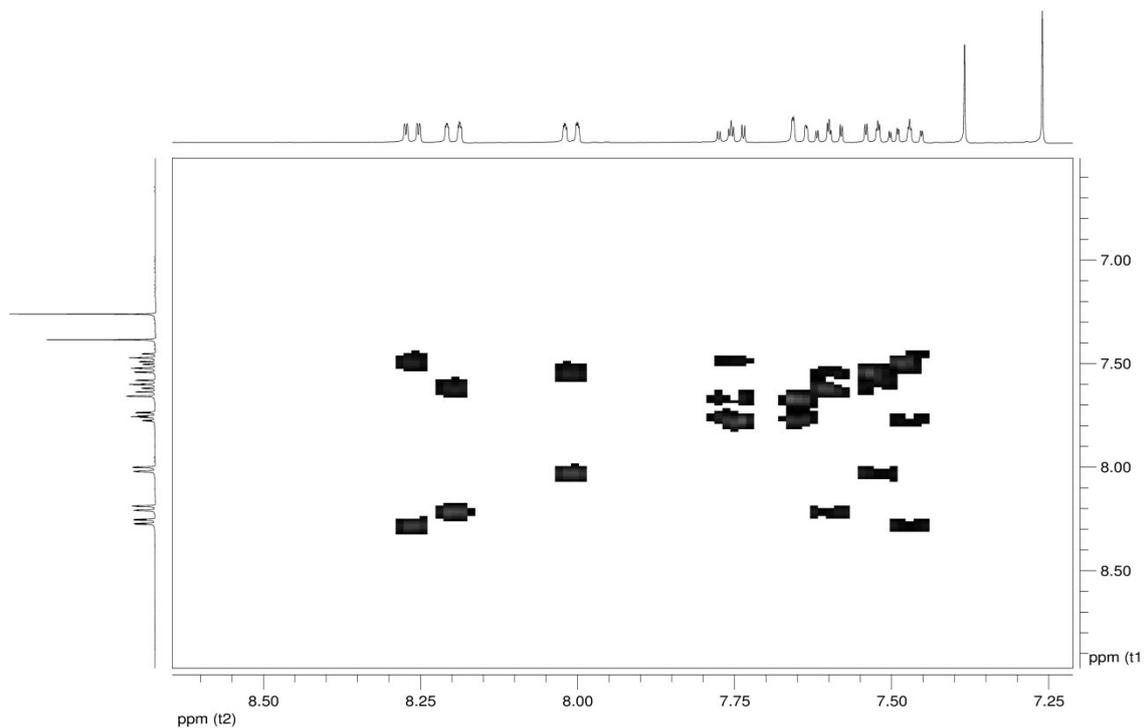
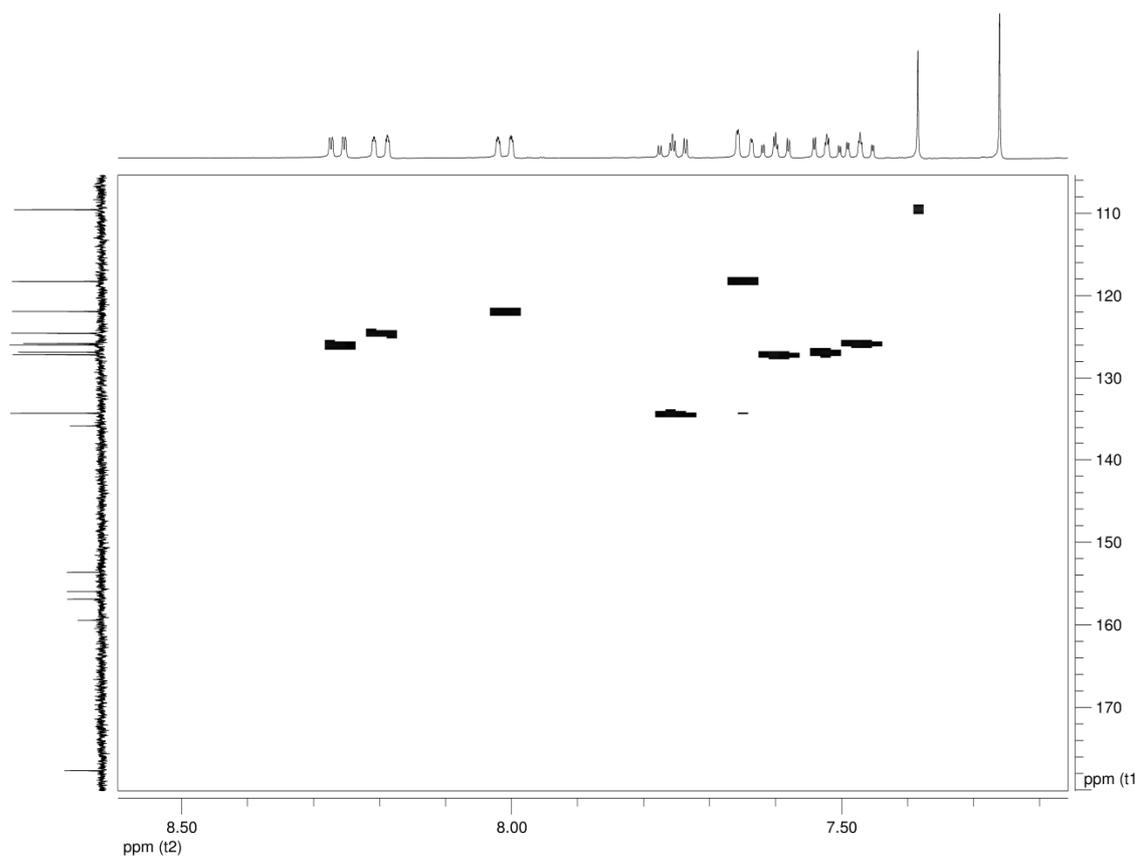Figure **S2**. 2D-NMR COSY spectra of 2-(benzo[d]thiazol-2-yl)-4H-chromen-4-one (**2**)

Figure **S3**. 2D-NMR HSQC spectra of 2-(benzo[*d*]thiazol-2-yl)-4*H*-chromen-4-one (**2**)
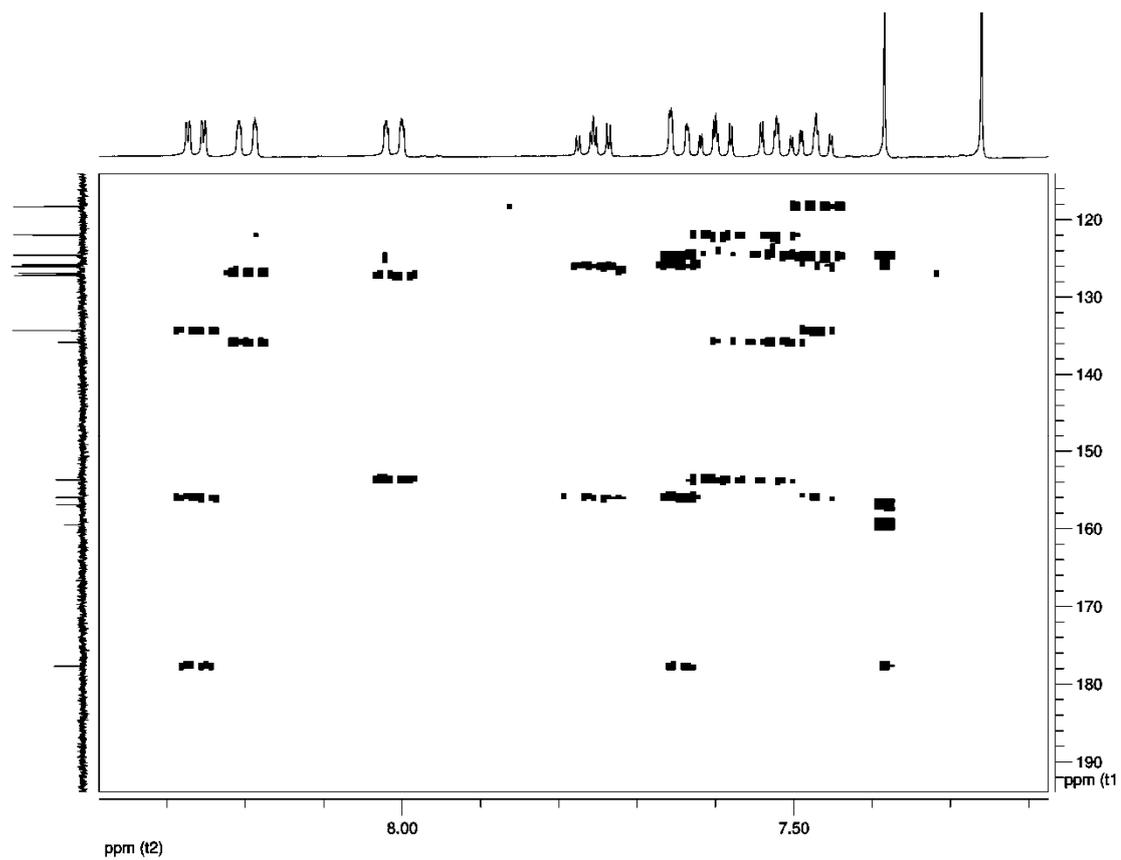
Figure **S4**. 2D-NMR HMBC spectra of 2-(benzo[*d*]thiazol-2-yl)-4*H*-chromen-4-one (**2**)
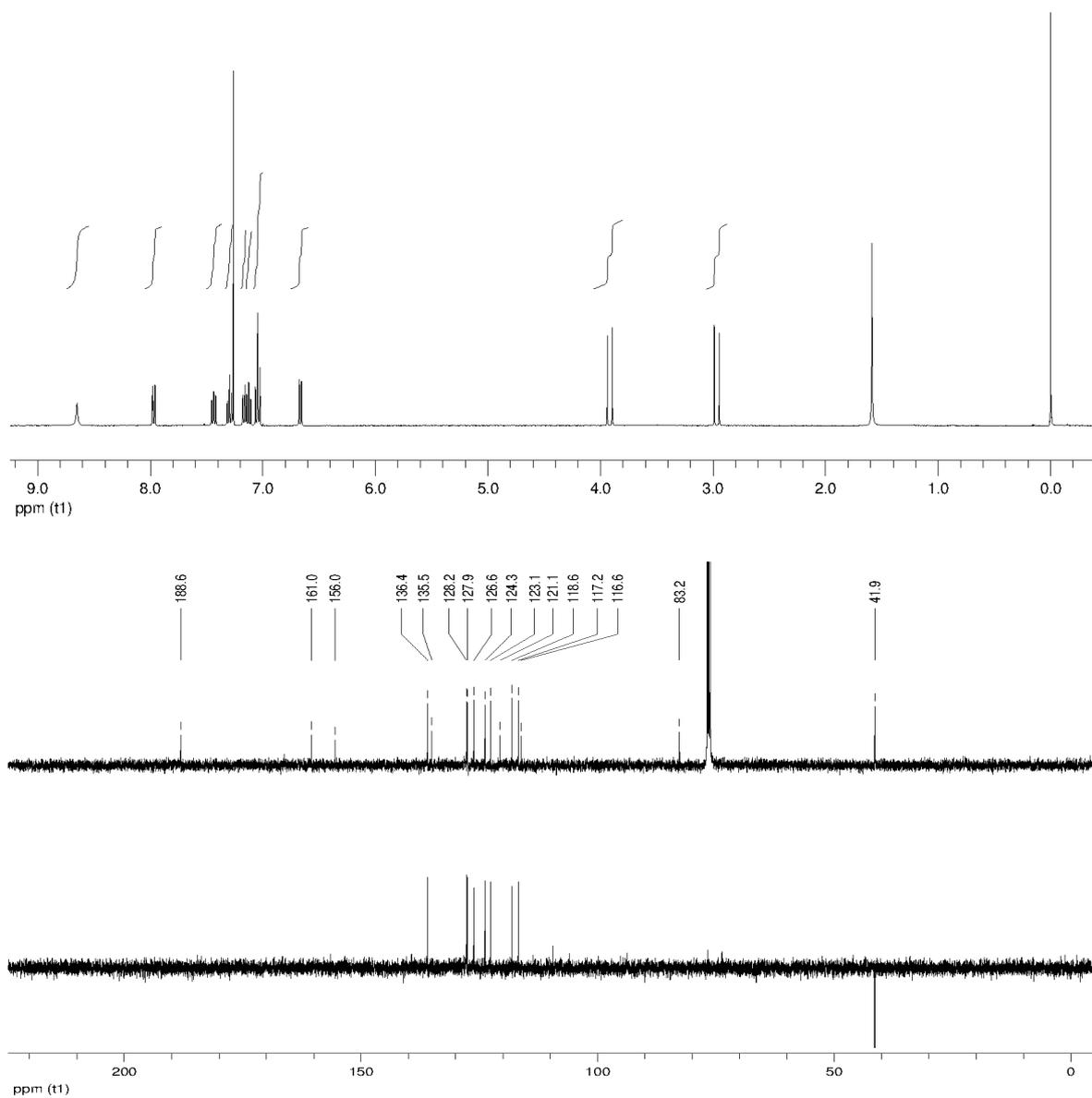
Figure **S5**. ^{1}H, ^{13}C and DEPT NMR spectra of spiro[benzo[*b*][1,4]thiazine-2,2'-chroman]-3,4'(4*H*)-dione (**3**)
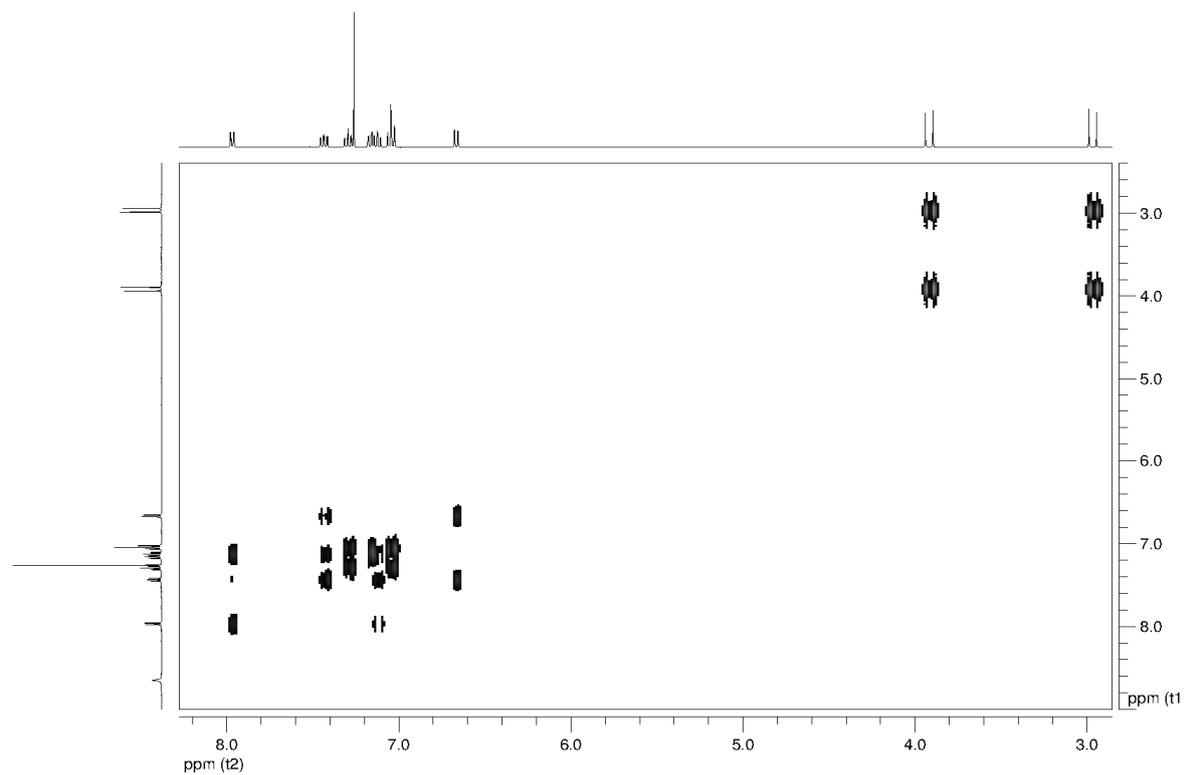
Figure **S6**. 2D-NMR COSY spectra of spiro[benzo[*b*][1,4]thiazine-2,2'-chroman]-3,4'(4*H*)-dione (**3**)
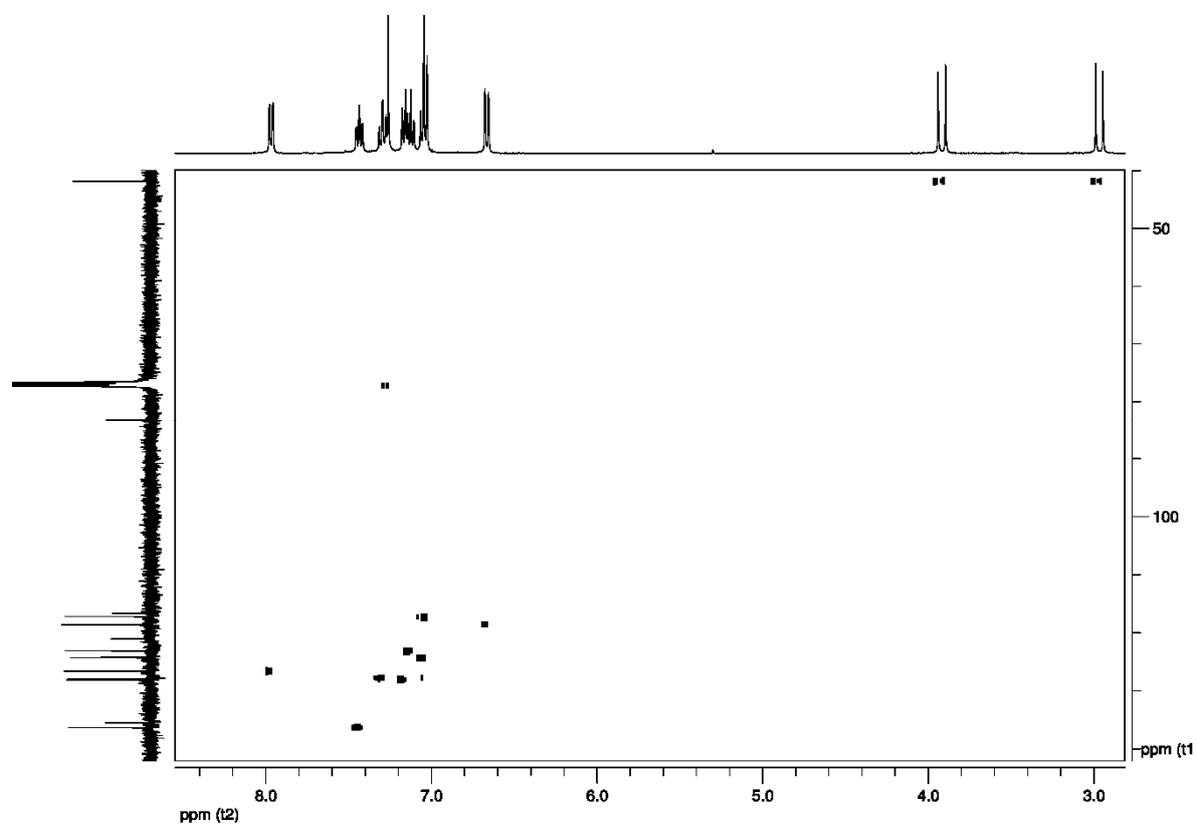
Figure **S7**. 2D-NMR HSQC spectra of spiro[benzo[*b*][1,4]thiazine-2,2'-chroman]-3,4'(4*H*)-dione (**3**)
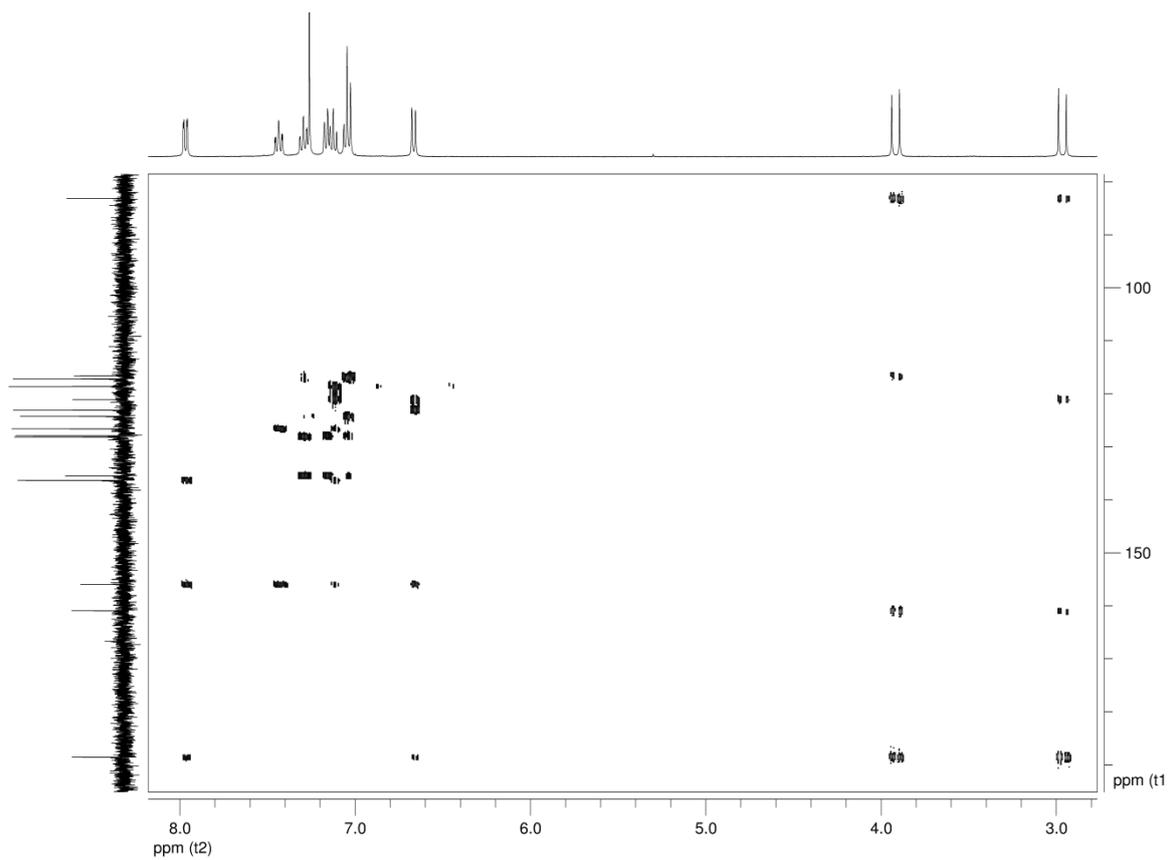
Figure **S8**. 2D-NMR HMBC spectra of spiro[benzo[*b*][1,4]thiazine-2,2'-chroman]-3,4'(4*H*)-dione (**3**)

Single crystal X-ray data and analysis

X-ray quality crystals of compounds (**1**), (**2**) and (**3**) were grown from CH_2Cl_2 solutions in at room temperature and by slow isothermal evaporation. Crystallographic data were collected on a Rigaku Saturn944+ diffractometer at 100 K and the structures were solved using the following computer programs: *CrystalClear-SM* Expert 2,[1] *SHELXS*,[2] *ShelXle*,[3] *SHELXL*,[2] *Mercury* ,[4] and *Platon*.[5] The details of the crystallographic analyses are given in Table S1. The H atoms were treated as riding atoms with C—H(aromatic) = 0.93Å, with Uiso = 1.2Ueq(C). The H attached to N2 in (3) was located on a difference Fourier map and was refined. The same procedure was carried out with the H atom of the carboxylic group of the chromone 2-carboxylic acid (**1**).

CCDC numbers 975960, 952953 and 952896 contain the supplementary crystallographic data for compounds (**1**), (**2**) and (**3**), respectively. These data can be obtained free of charge from the Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

Table S1. Experimental details for X-ray Analyses

Crystal data	(1)	(2)	(3)
Chemical formula	$C_{10}H_6O_4$	$C_{16}H_9NO_2S$	$C_{16}H_{11}NO_3S$
M_r	190.15	279.30	297.32
Crystal system, space group	Monoclinic, $P2_1/n$	Monoclinic, Pc	Monoclinic, $P2_1/c$
a, b, c (Å)	3.7382 (2), 18.6473 (13), 11.3384 (8)	17.3778 (11), 4.7950 (2), 22.3327 (16)	13.9905 (10), 5.2882 (4), 18.5867 (13)
β (°)	91.370 (5)	97.629 (2)	107.084 (5)
V (Å^3)	790.14 (9)	1844.43 (19)	1314.45 (16)
Z	4	6	4
Radiation type	Mo $K\alpha$	Mo $K\alpha$	Cu $K\alpha$
μ (mm^{-1})	0.13	0.26	2.28
Crystal size (mm)	$0.13 \times 0.11 \times 0.02$	$0.14 \times 0.02 \times 0.01$	$0.35 \times 0.06 \times 0.01$

Data collection

Diffractometer	Rigaku Saturn724+ (2x2 bin mode) diffractometer	Rigaku Saturn724+ (2x2 bin mode) diffractometer	Rigaku Saturn944+ (2x2 bin mode) diffractometer
Absorption correction	Multi-scan *CrystalClear*-SM Expert 3.1 b27 (Rigaku, 20112)	Multi-scan *CrystalClear*-SM Expert 3.1 b25 (Rigaku, 20112)	Multi-scan *CrystalClear*-SM Expert 3.1 b27 (Rigaku, 20112)
T_{min}, T_{max}	0.984, 0.998	0.964, 0.997	0.502, 0.978
No. of measured, independent and observed [$I > 2\sigma(I)$] reflections	7946, 1798, 1334	23237, 8086, 7273	9601, 2289, 2112
R_{int}	0.056	0.046	0.032
$(\sin \theta/\lambda)_{max}$ (Å^{-1})	0.649	0.649	0.603

Refinement

$R[F^2 > 2\sigma(F^2)]$, $wR(F^2)$, S	0.039, 0.103, 1.02	0.034, 0.074, 1.02	0.043, 0.112, 1.17
No. of reflections	1798	8086	2289
No. of parameters	131	541	194
No. of restraints	0	2	0
H-atom treatment	H atoms treated by a mixture of independent and constrained refinement	H-atom parameters constrained	H atoms treated by a mixture of independent and constrained refinement
$\Delta\rangle_{max}$, $\Delta\rangle_{min}$ (e Å^{-3})	0.27, -0.30	0.23, -0.20	0.51, -0.34
Absolute structure	–	Flack H D (1983), Acta Cryst. A39, 876-881	–

| Absolute structure parameter | – | -0.01 (4) | – |

Compound **(2)** crystallised with 3 molecules in the asymmetric unit, ellipsoid plots of the 3 molecules. The molecules are identified as molecule #1, #2 and #3 in accordance with the first number of the labels of their atoms. The 3 molecules are nearly planar as expected taking in account the possibility of the electronic delocalization due to aromaticity and conjugation. From the set, molecule #2 is the less planar as can be evaluated by the torsion and dihedral angles presented in Table **2a** (dihedral angle between the chromone and the benzothiazole ring is 11.69(6)° for that molecule whereas for the others the corresponding values are 4.98(6)° and 2.15(6)° for molecules # 1 and #3 respectively).

Table S2a Selected torsion angles (º) and dihedral angles between chromone and benzothiazole rings.

Torsion Angle	#1	#2	#3
Cn3—Cn2—Cn22—Nn23	-5.4 (3)	9.4 (3)	1.3 (3)
On1—Cn2—Cn22—Nn23	174.84 (19)	-172.91 (19)	-178.96 (19)
Cn3—Cn2—Cn22—Sn21	174.22 (17)	-168.54 (17)	-178.04 (17)
On1—Cn2—Cn22—Sn21	-5.6 (2)	9.1 (2)	1.7 (2)
Dihedral angle	4.98(6)	11.69(6)	2.15(6)

The slight differences in torsions angles of molecule #2, in compound **(2)** with respect to the others, are reflected on the MOLFIT with Quaternion Transformation Method[5,6] calculations (Table S2b). MOLFIT allows the comparison of the structures of two molecules by referring the molecules to their centres of gravity and by rotating them using a unit quaternion to find the best fit of one molecule or the inverted molecule with respect to the other by least squares calculations. The weights used are related to the distances of atoms from the centre of gravity. The maximum separation between corresponding atoms were 0.226Å for O14 and O24, for molecules #1 and #2; 0.073Å for S121 and S321, for molecules #1 and #3; 0.217Å for C227 and C327, for molecules ##2 and #3, showing that the pair #1/#3 gives the best fit.

Table S2b MOLFIT values (Å) for the 20 non-hydrogen atoms, PLATON [5] and [6].

Molecules	RMSD(weighted)Å	RMSD(unweighted)Å
1* and 2	0.111	0.099
1* and 3	0.053	0.050
2 and 3	0.128	0.115

* Indicates the inverted molecule was used in the fit.

Supramolecular Structures Analysis

Table S4 gives details of the hydrogen bonding for the compounds under study. In compound (1) the O22–H22···O4(1/2+x,3/2-y,1/2+z) links the molecules into C7 chains, [7] which run parallel to [101]. The molecules are also linked by the weak C6–H6···O22(-x-1/2, y-1/2, -z+1/2) and C7–H7···O21(1-x,1-y,1-z) hydrogen bonds. These three interactions link the molecules to form a three-dimensional network The molecules are $\pi\cdots\pi$ stacked along the a-axis, with a separation of 3.7382 (9)Å between the pyran mean planes and the same separation between the phenyl ring mean plane. The perpendicular distance between the pyran mean planes is 3.545 (6)Å and the slippage is 1.650Å. The corresponding distances for the benzene rings are 3.3419Å and 1.675Å (Figures S10 and S11).

In compound (2) the C-H•••O intermolecular interactions are those which link the molecules in the asymmetric unit. Probably the most interesting feature of the supramolecular structure for this compound is the amount of $\pi•••\pi$ interactions between its rings. Table S5 lists all possible $\pi•••\pi$ interactions with a centroid to centroid distance less than 4.0Å. This shows that there are no stacking interactions between molecules 1 and 2, 1 and 3 or 2 and 3 and that in each case the stacking forms a similar pattern in each case along the b-axis. Thus, there are no stacking interactions between molecules with different labels. Figure S13 shows that the molecules #3 stack with themselves. The same kind of stacking is observed for molecules #1 and #2, in each case, the stacking forms a similar pattern along the b-axis.

In compound (3) the molecules are linked by an N—H...O hydrogen bond to form an $R_2^2(8)$, [7], centrosymmetric dimer across the centre-of -symmetry at (1,0,1/2) (Figure S14)-

Table S4. Selected hydrogen-bond parameters.

D—H···A	D—H (Å)	H···A (Å)	D···A (Å)	D—H···A (°)
(1)				
O22—H22···O4[i]	0.99 (2)	1.60 (2)	2.5857 (15)	170 (2)
C6—H6···O22[ii]	0.95	2.57	3.4254 (18)	150
C7—H7···O21[iii]	0.95	2.49	3.2402 (19)	136
(2)				
C17—H17···O34[iv]	0.95	2.51	3.147 (3)	125
C36—H36···O24[v]	0.95	2.53	3.473 (3)	172
(3)				
N4—H4···O9[vi]	0.86 (3)	2.12 (3)	2.970 (2)	174 (3)

Symmetry code(s): (i) $x+1/2$, $-y+3/2$, $z+1/2$; (ii) $-x-1/2$, $y-1/2$, $-z+1/2$; (iii) $-x+1$, $-y+1$, $-z+1$; (iv) $x-1$, $y-1$, z; (v) x, $-y+2$, $z-1/2$; (vi) $-x+2$, $-y$, $-z+1$.

Table S5. Analysis of Short Ring-Interactions with Cg-Cg Distances less than 4.0 for (**2**)

Cg(I)	Cg(J)(aru)	Cg-Cg(Å)	α(°)	CgI_Perp(Å)	CgJ_Perp(Å)
1	2(x,y+1,z)	3.8798(12)	5.07(10)	-3.2245(8)	3.3926(8)
1	3(x,y-1,z)	3.7198(12)	0.81(10)	3.4199(8)	-3.4209(9)
2	4(x,y+1,z)	3.4876(13)	0.56(10)	-3.3169(8)	3.3159(9)
7	8(x,y+1,z)	3.7153(12)	10.56(10)	-3.4715(8)	3.1845(9)
7	9(x,y-1,z)	3.7206(12)	2.85(10)	3.3767(8)	-3.3890(9)
8	10(x,y+1,z)	3.6880(13)	1.31(10)	-3.4701(9)	3.4407(9)
13	14(x,y-1,z)	3.9385(12)	2.11(10)	3.2534(8)	-3.3328(8)
13	15(x,y+1,z)	3.7110(13)	0.53(10)	-3.3381(8)	3.3444(9)
14	16(x,y-1,z)	3.4904(13)	0.79(10)	3.3271(8)	-3.3329(9)

Cg(I) = Plane number I or J; α = Dihedral Angle between Planes I and J ; Cg-Cg = Distance between ring Centroids (Å); CgI_Perp = Perpendicular distance of Cg(I) on ring J (Å); CgJ_Perp = Perpendicular distance of Cg(J) on ring I (Å)
Cg1 is the centroid of ring S121-C17A-C13A-N123-C122
Cg2 is the centroid of ring O11-C12-C13-C14-C14A-C18A
Cg3 is the centroid of ring C14A-C15-C16-C17-C18-C18A
Cg4 is the centroid of ring c13A-C17A-C127-C126-C125-C124
Cg7 is the centroid of ring S221-C27A-C23A N223-C222
Cg8 is the centroid of ring O21-C22-C23-C24-C24A-C28A
Cg9 is the centroid of ring C24A-C25-C26-C27-C28-C28A
Cg10 is the centroid of ring C23A-C27A-C227-C226-C225-C224
Cg13 is the centroid of ring S321-C37A-C33A-N323-C322
Cg14 is the centroid of ring O21-C32-C33-C34-C34A-C38A
Cg15 is the centroid of ring C34A-C35-C36-C37-C38-C38A
Cg16 is the centroid of ring C33A-C37A-C327-C326-C325-C324

References

[1] Rigaku CrystalClear SM Expert 2.0 r13, Rigaku Corporation, Tokyo, Japan, **2011.**

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[5] Mackay, A.L. *Acta Cryst.* **1984**, A40, 165-166.

[6] Spek, A. L. *Acta Cryst.* **2009**, *D65*, 148.

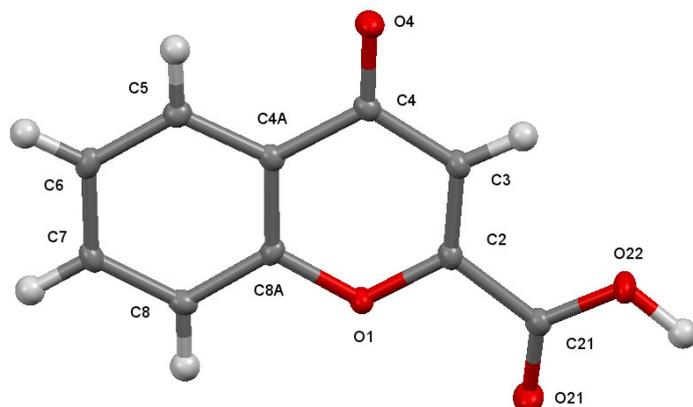[7] Bernstein, J.; Davis, R. E.; Shimoni, I.; Chang, N. L. *Angew. Chem. Int. Ed. Engl.* **1995**, 34, 1555.

Figure **S9.** Thermal ellipsoid (70%) plot of the molecule of chromone-2-carboxylic acid (**1**)
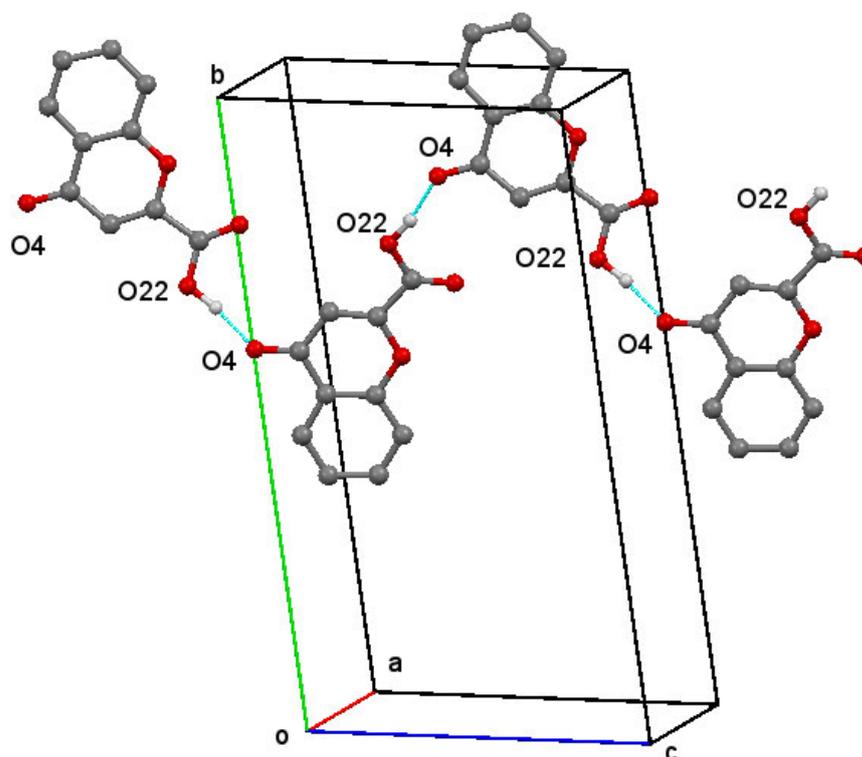
Figure **S10**. The C7 chain formed by the O22-H22...O4 hydrogen bond in chromone-2-carboxylic acid (**1**). Hydrogen atoms not involved in the hydrogen bonding are omitted.
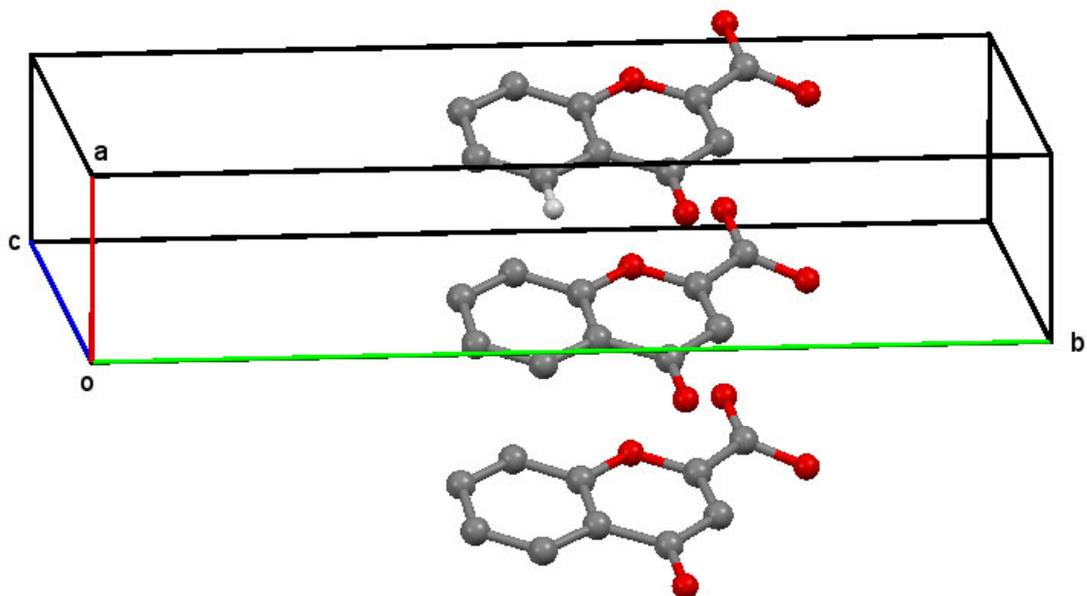
Figure **S11**. π...π Stacking, along the a-axis, of the molecules of chromone-2-carboxylic acid (**1**) along the a-axis. Hydrogen atoms are omitted.
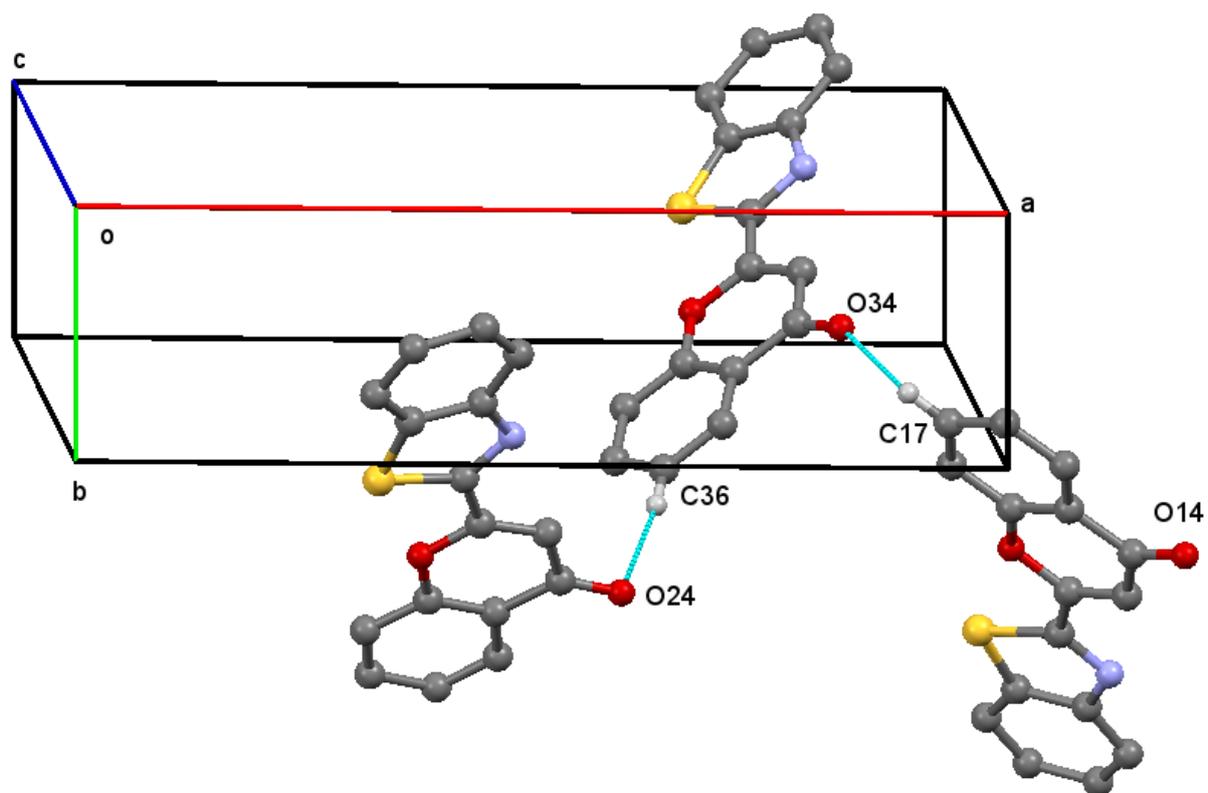
Figure **S12.** The trimer formed by the hydrogen bonding of 2-(benzo[d]thiazol-2-yl)-4H-chromen-4-one (**2**). Hydrogen atoms not involved in the hydrogen bonding are omitted.
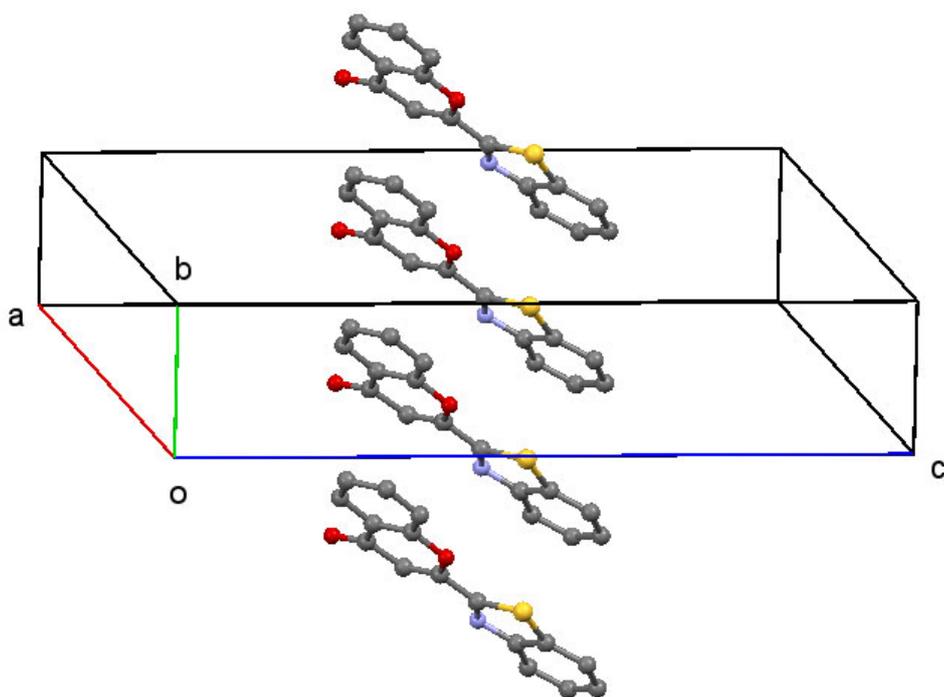
Figure **S13**. π...π stacking, along the b-axis, of molecule 3 of 2-(benzo[d]thiazol-2-yl)-4H-chromen-4-one (**2**).   The stacking of molecules 2 and 3 is similar. Hydrogen atoms are omitted.
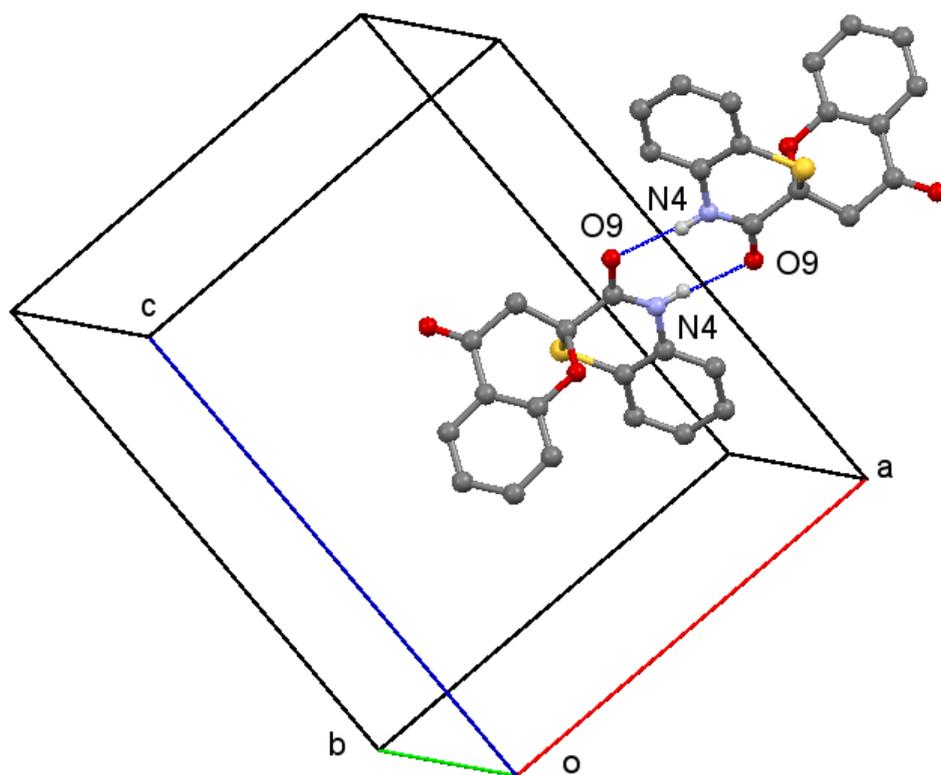
Figure **S14.** The centrosymmetric dimer formed by the hydrogen bonding of spiro[benzo[*b*][1,4]thiazine-2,2'-chroman]-3,4'(4*H*)-dione (**3**). Hydrogen atoms not involved in the hydrogen bonding are omitted.